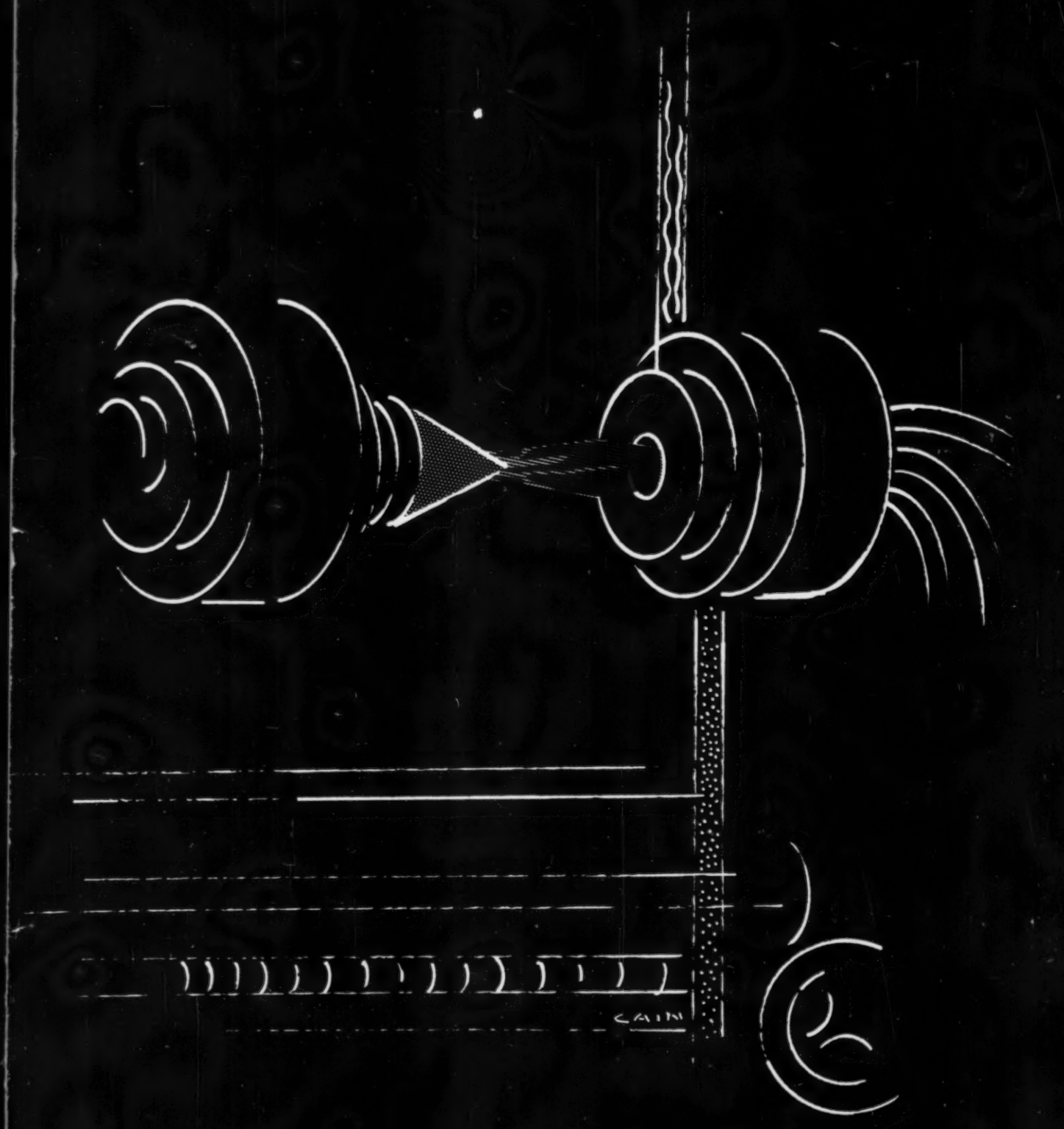
JOURNAL OF

METALS

JULY 1961



Pre-Engineering by **KAISER ENGINEERS** answers basic plant expansion questions...

Raw Materials?

Your final decision to expand or build results from a series of important individual decisions. Raw material availability is one of them. Independent analysis of all aspects of your proposed program is the *Pre-Engineering* service offered by Kaiser Engineers. In addition, KE designs and builds for the Steel industry... offers skilled experience in all types of facilities from raw material plants to finishing mills. Whatever your requirements... from Pre-Engineering analyses through plant design and construction... Kaiser Engineers brings world-wide experience and ingenuity to their solution.

KAISER ENGINEERS

KAISER ENGINEERS engineers - contractors
Contracting since 1914

Oakland 12, Calif. — Chicago, New York, Pittsburgh, Washington, D.C.
Accra, Buenos Aires, Montreal, New Delhi, Rio de Janeiro, Sydney, Vancouver, Zurich

8231-5

JOURNAL OF

METALS

Vol. 13, No. 7
July, 1961

COVER: Application of the Plasma Arc to Metallurgy is the theme of this issue and the cover by David Cain. Articles are drawn from the AIME sponsored sessions of the 1961 Western Metals Congress.

contents 453
personnel 454
around the sections 456
engineering consultants 456
education 458
books 460
personals 462
reporter 467
letters to editor 470
editorial 471
news of your profession 508
know your society 512
advertisers index 516
coming events 516

Metallurgy of Semiconductors Materials Program 465
JUNE TRANSACTIONS CONTENTS 469

PLASMA ARC APPLICATIONS:
Process Variables in Plasma-Jet Spraying 473
by D. R. Mash, N. E. Weare, and D. L. Walker
Plasma Spraying Techniques for Toxic and Oxidizable Materials 479
by A. R. Stetson and C. A. Hauck
Tungsten Fabrication by Arc Spraying 483
by R. H. Singleton, E. L. Bolin, and F. W. Carl

REFRACTORY METALS:
Tantalum Alloys for Elevated-Temperature Service 487
by F. F. Schmidt, D. J. Maykuth, and H. R. Ogden
Low-Pressure, High-Temperature Oxidation of Tungsten 490
by R. A. Perkins and D. D. Crooks
Tungsten-Columbium-Tantalum Alloys 494
by J. L. Wilson and C. R. McKinsey
Blast Furnaces, Coke Ovens, and Liberty Bells! 497
Part IV. History of the Coking Industry in the United States 501
by C. S. Finney and John Mitchell
High-Temperature Materials Conference 504

PHASES AND PROCESSES:
Rare Earth Horizons 506
by L. D. Lash

EDITORIAL STAFF: Editor in Chief, F. Weston Starratt; **Associate Editor,** Edward Fitzgerald, **Production Editor,** Otto Johnson; **News Editor,** William Leggitt; **Editorial Assistant,** C. M. Cardon.
ADVERTISING SALES MANAGER: Lee Kent, 122 East 42nd St., New York 17, N. Y.
WESTERN ADVERTISING REPRESENTATIVE: Dillenbeck-Galavan Inc., 266 S. Alexandria Ave., Los Angeles 4, Calif.

Address insertion orders and copy to: Advertising Department, JOURNAL OF METALS, 29 West 39th Street, New York 18, N. Y. Send plates to: JOURNAL OF METALS, C/O Lew A. Cummings Co., Inc., 215 Canal St., Manchester, N. H. Published the first day of each month by the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9220. Subscription $10 per year for non-AIME members in North, South & Central America, $12 elsewhere; $6 for AIME members, or $4 additional for members, only in combination with a subscription to "Mining Engineering" or "Journal of Petroleum Technology." Single copies, $1.50. The AIME is not responsible for any statement made or opinions expressed in its publications . . . Copyright 1961 by the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. . . . Registered address, AIME New York . . . Indexed in Engineering Index, Industrial Arts Index, and Chemical Abstracts . . . Second class postage paid at New York, N. Y., and at Manchester, N. H. Numbers of copies in this issue, 12,300.

personnel

- These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the societies of Civil, Electrical, Chemical Mechanical, Mining, Metallurgical, and Petroleum Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 60% of the first month's salary if a non-member, 50% if a member. Also, that you will agree to sign our placement fee arrangement which will be mailed to you immediately after receiving your application. In sending applications be sure to list the key and job number.
- When making application for a position, include eight cents in stamps for forwarding application to the employer and for returning, when possible.

MEN AVAILABLE

Sales Engineer, BS ChE, age 49. Fifteen years in Midwest area as sales and technical service engineer promoting the use and sale of metallic nickel, titanium and zirconium alloys, refractories, chemicals and ceramics. Prefer No. Indiana and Chicago area. M-2191-Chicago.

Metallurgist, MetE, age 41. Master degree of science in metallurgical engineering, ten years in ferrous metal smelting and three years research work in physical metallurgy. Any location. Home: California. $600. Se-1873.

Technical Engineer, MetE, age 23. Recent graduate with nine months experience in metals on problems with vacuum power tubes, on control rods, on production problems, quality control of materials using government specifications. Prefer San Francisco area. Home: California. $450. Se-1703.

POSITIONS OPEN

Metallurgist, graduate, for plant metallurgy on moulds subjected to high temperature, fatigue testing, metal compositions, coating and plating and corrosion problems. $9000-$11,000. New York State. W393.

Welding Supervisor, preferably with degree in metallurgical engineering or related field, familiar with arc welding methods in steel and alloy fabrication; 3 years welding and metal fabricating operations. $7000-$9000. Midwest. W379(a).

Process Engineer, degree in mechanical, metallurgical engineering or metallurgy, with experience in primary metal processing, casting, extrusion, rolling, drawing, etc., to work in development of physical facilities and mechanical methods for new mill products and in the improvement of existing processes, equipment, and products. Understanding of economics of mill operations desirable. $6500-$9000 year. Southwestern Connecticut. W376.

Physical Metallurgist, Ph.D., with 5 to 10 years of pertinent experience in physical metallurgy, including a working knowledge of the physics and chemistry of solids, for research primarily on rare earth and thorium metals and alloys. To $15,000 year. New Jersey. W358.

Factory Manager, 40-50 some background in metallurgy with heavy experience in factory production and control for company manufacturing precious metals and wire. $10,000-$12,000 year. Suburban New York. W345.

Research Metallurgist, preferably with advanced degree, for work on physical metallurgy and metals research for independent research organization. Should be able to originate, organize and supervise research projects in this field. Salary open. Rocky Mountain area. W316S.

Designers, metallurgical and electrical engineers, with specific experience in the design of iron and steel producing plants. Operating steel plant experience desirable. Salary open. New York City. W310.

Metallurgist, Foreman, $7200, in Nevada, graduate preferred, age open. Prefer experience in cyanide plant operations. Housing available. For an operating company. Sj-5813.

Sr. Nonferrous Metallurgical Engineer, for staff position covering consultant and project design responsibilities in the fields of base metal pyro, hydro, and electro-metallurgy. Recent wide plant experience in R&D or operation is a basic qualification. $12,000-$15,000 year. New York City. W8630.

Metallurgist experienced in the preparation of research materials and laboratory techniques of physical metallurgy. Work will include zone melting, crystal growing, vacuum melting and casting, common melting and forming operations; supervision and expansion of equipment. Salary open. Chicago, Illinois area. W303C.

Manager, metallurgical or chemical degree, to build and operate an aluminum sulfate plant. Prefer experience in construction chemical plants. Will handle plant and mine and native laborers. Should have had Latin American experience and speak Spanish. Salary open. South America. F286.

Teaching Position, Physical Metallurgist, with teaching and industrial experience. Ph.D. degree essential, also recognized research publications. Will teach undergraduate and graduate students and direct graduate student research. Salary and rank commensurate with experience and proven ability. Available September, 1961. East. W272.

Junior Metallurgists for ore dressing, either recent graduates or with a few years experience for investigation in processes in magnetic, gravity and flotation for recovery of ilmenite in a 7000 tpd concentrator. Salary commensurate with experience. East. W258.

Metallurgical Engineers who have specialized in selling hard surfacing materials to the welding industry. Traveling and relocation will be involved. $10,000 year. Headquarters, New York City. W252.

Research Metallurgist, preferably with M.S. in electro-chemistry, for metallurgical research project. $7000 year. Long Island, N.Y. W313.

Teaching Position in Department of Metallurgical Engineering; extractive metallurgist, mostly for research and graduate student supervision with limited amount of teaching. Ph.D. in metallurgy or a closely related field, interested in the application of physical chemistry to metal extraction and refining; or in the application of chemical engineering concepts to metal extraction and refining. Rank and salary dependent upon qualifications. Canada. F408.

Quality Control Engineer, about $700, in Stockton Calif.; graduate Chem, MetE, age to 35. Preferably experienced in quality control (laboratory, plant, process) in high speed, mechanized can making for a foods plant. Should be knowledgeable about plating, coating, sealing. Able to carry out laboratory work, set up standards, install quality control procedures, provide continuing assurance of controlled processing and end product. For a manufacturer of metal cans for food processing. Sj-6159.

Foundry Superintendent, about $1000, in Philippines, MET or ME, age to 55. Solid recent and continuous experience in all phases of modern manganese steel foundry operations (electric furnaces, shakeout equipment, finishing, complete laboratory, melting, pouring, casting). For a newly equipped foundry. Sj-6147.

Research Metallurgist, salary commensurate, in Colorado. Prefer advanced degree. Work on physical metallurgy and metals research. Should be able to originate, organize and supervise research projects in this field. For an independent research organization. Sj-6131.

Production Engineer, $8000-9000, in Nevada, ME, MET, IE, Chem, age 25-30. Three to five years smelting and refining nonferrous metals, experienced in ingot production, process procedures, quality control, general metallurgy, reduction plant layout involving heavy crushers, leaching, chlorine, vacuum arc furnace melting and heavy bulk materials handling from ore to ingot. For a large mill. Sj-6111.

Address replies for positions to the nearest local office of the Engineering Societies Personnel Service, Inc., *not* to the JOURNAL OF METALS. Offices are located at 29 E. Madison St., Chicago 1, Ill. . . . 57 Post St., San Francisco, Calif. . . . and 8 W. 40th St., New York 18, N. Y.

a new book

of special interest to the nuclear metallurgist . . .

published under the sponsorship of The Metallurgical Society of AIME

Extractive and Physical Metallurgy of Plutonium and its Alloys

The Proceedings of a Technical Symposium sponsored by the Nuclear Metallurgy Committee of the Institute of Metals Division, and the Titanium, Uranium, and Uncommon Metals Committee of the Extractive Metallurgy Division, The Metallurgical Society of AIME. San Francisco, February 16-17, 1959.

Edited by W. D. WILKINSON, Argonne National Laboratory

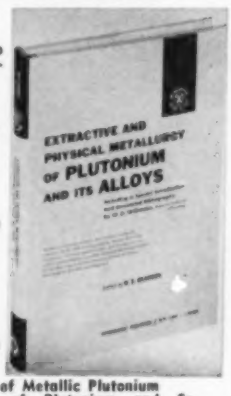
The addition to these Proceedings of an introductory chapter on the metallurgy of plutonium and of an extensive annotated bibliography has made this volume of even greater value to metallurgists working in this particularly important field. Mr. Wilkinson both edited the Proceedings and provided the new material.

CONTENTS

Introduction to Plutonium Metallurgy

EXTRACTIVE METALLURGY

- Alternative Routes for the Conversion of Plutonium Salts to Metal and Their Recovery Problems
- Calcium Reduction of Plutonium Halides to Metal
- Preparation of Metallic Plutonium
- Distribution of Plutonium and Selected Impurity Elements between Nitrate Solutions and Tri-n-butyl Phosphate
- The Preparation of Plutonium Halides for Fused Salt Studies
- Removal of Fission Product Elements from Plutonium by Liquidation



PHYSICAL METALLURGY

- Some Principles of the Alloying Behavior of Plutonium
- The Plutonium-Cerium Diagram
- Plutonium-Zinc Phase Diagram
- Metallography of Alpha Plutonium
- The Etching of Plutonium and Its Alloys by Cathodic Bombardment
- A Study of the Transformation Kinetics of Alpha, Beta, and Gamma Plutonium
- Some Experiments in Zone Refining Plutonium
- Behavior of Some Delta-Satilized Plutonium Alloys at High Pressure
- Annotated Bibliography

324 pages, illustrated $10.50

through your bookseller or

INTERSCIENCE PUBLISHERS

250 Fifth Avenue, New York 1

METALGRAMS

. . . news of "Electromet" ferroalloys and metals

UNION CARBIDE METALS

JULY 1961

MAKING MORE PERFECT METALS -- Vacuum melting is meeting the higher property requirements of space and atomic uses. This young, growing industry is producing steels and superalloys with better properties than those melted in air. These vacuum-melted alloys have better ductility, impact strength, fatigue strength, and rupture and magnetic properties. Vacuum melters are also making superalloys and ultra-pure metals that cannot be melted in air. These metals and alloys have produced impressive results. Ball-bearing life has doubled. Jet engines operate longer at higher temperatures. Nuclear reactors can run efficiently.

* * *

ALLOYS FOR VACUUM MELTING -- Union Carbide Metals supplies a complete range of ferroalloys and metals for steels and superalloys melted by both major vacuum-melting processes. In vacuum-arc melting, an air-melted electrode is remelted to improve purity and uniformity. Ferroalloys must be added during air melting since vacuum-arc melting does not allow alloy adjustments. In vacuum-induction melting, alloy additions are made in the vacuum furnace. Metals such as "Elchrome" electrolytic chromium and "Elmang" electrolytic manganese are desired for such additions because of their purity. For more information, call your Union Carbide Metals representative today. Also, ask for the article, "Making More Perfect Metals," in the Summer 1961 issue of UNION CARBIDE METALS REVIEW.

* * *

ULTRA-PURE METALS, TOO -- UCM also offers ingots of columbium, tantalum, and vanadium metal made by a new vacuum process -- electron-beam melting. The electron-beam process provides the purity needed to make these metals ductile and easily formable. All three metals have one property of wide interest to metallurgists -- high strength at elevated temperatures. Thus, they may be the key to future hypersonic flight vehicles. The three metals also resist corrosion. In fact, tantalum chemical equipment resists both oxidizing and reducing media better than most other materials. Columbium effectively resists molten salts. Other properties: columbium and vanadium have moderate neutron cross-sections, allowing use in nuclear reactor structures. Tantalum has ideal dielectric properties for electronic capacitors. Your UCM representative can give you further information and literature on each of these metals.

* * *

UNIQUE VACUUM PROCESS...BETTER ALLOY ADDITIONS -- In the world's largest vacuum furnaces at Marietta, Ohio, UCM eliminates certain hard-to-remove elements from ferroalloys and metals. They aren't removed by melting. They are removed by refining in the solid state. For example, carbon is virtually eliminated from "Simplex" ferrochrome, allowing carbon-free additions to stainless steel. Gases are removed from "Elchrome" VG chromium metal. Thus, less gas is evolved when the metal is used in vacuum-induction melting. Also, nitrogen is added to certain chromium and manganese alloys...for convenient nitrogen additions to stainless steel. Learn more about this unique vacuum process by writing for the article, "The Silent World of SIMPLEX," in the Summer 1960 issue of UNION CARBIDE METALS REVIEW.

* * *

UNION CARBIDE METALS COMPANY, Division of Union Carbide Corporation, 270 Park Ave., New York 17, N. Y. In Canada: Union Carbide Canada Ltd., Toronto.

"Elchrome," "Elmang," "Simplex," "Electromet," and "Union Carbide" are registered trade marks of Union Carbide Corporation.

engineering consultants

ENGINEERING CONSULTANTS FOR THE ALUMINUM INDUSTRY

Specialists in Manufacturing & Equipment Builders of Fine Equipment

Continuous Sheet and Billet Casters
Sheet and Foil Rolling Mills
Sheet Painting and Coating Equipment
Billet Saws, Roll Formers, Embossers
Special Equipment

Hunter Engineering Co. • P. O. Box 272 • Riverside, Calif.

PROPANE GAS PLANTS
ANHYDROUS AMMONIA PLANTS
Designed and Installed
PEACOCK CORPORATION
Box 268, Westfield, N. J.

OX7-6090
PROMOTION ASSOCIATES
Engineering Writers
Preparation of Articles • Reports
Sales Literature • Technical Advertising
122 East 42nd Street, New York 17, N.Y.

EUROPE
Technical Information and Liaison Services are available from a Professional Engineer Resident in the U.K.
Write Box JM, Journal of Metals
29 W. 39th Street, New York 18, N. Y.

OI 3-0078
Conrad A. Parlanti
11 Bradford Road
Natick, Massachusetts
Metallurgy — Foundry
Electronics — Materials

Announcements of specialized services published in this section at the rate of $60.00 per inch per year (12 consecutive issues). Send your order and copy to **JOURNAL OF METALS** Adv. Dept. EC, 122 East 42nd Street, New York 17.

AROUND THE SECTIONS

C. L. Sollenberger (left) and student Robert Yazell observed a high temperature stress analyzer with Prof. D. J. Mack in the foundry shop during the Wisconsin section's visit to the University of Wisconsin.

Wisconsin section, AIME, is making an effort to inform and interest high school students in mining and metallurgy. On May 18, a group of Milwaukee area students, interested in engineering, were invited to view the laboratory facilities in the Mining and Metallurgical Building on the University of Wisconsin campus.

The section has recognized that there is a growing shortage of students entering the mining and metallurgy fields, and professors confirmed that there is such a shortage at Wisconsin.

Following the tour of the buildings, the students attended the AIME meeting. Prof. Philip Rosenthal, head of the Mining and Metallurgy Dept., introduced his colleagues, who explained their particular areas of teaching and research. Those speaking included Profs. R. W. Heine, D. J. Mack, L. D. Clark, F. H. Vitovec, T. D. Tiemann, R. A. Dodd, R. R. Nelson, Carl Loper, Jr., and P. Rosenthal.

A dinner was held at the Cuba Club in the evening with chairman T. G. Kirkland acting as host. Guest speaker was Robert Marshall, associate dean of the College of Engineering. He told the group about the latest equipment available to engineering students, and the newest concepts in class instruction.

Section members and professors have decided to sponsor the trip on a yearly basis.

Pittsburgh section, AIME, held a dinner meeting May 10 at the Gateway Plaza Restaurant. The guest speaker for the evening was Russ Schell of National Supply Co. He discussed *Some Comparisons—Mineral Fuels and the U.S. Economy.*

San Francisco section, AIME, met May 10 at the Engineer's Club to hear a talk by R. R. McNaughton, President of AIME, who discussed *The Extractive Metallurgy of Lead, Zinc, and Silver.*

The section meeting on April 12, with 99 members and guests attending, featured a talk by Kirk Carlton, of the Lake Belt Co.'s Mining div. His subject was *Mining With the Bucket Wheel Excavator.*

Pittsburgh section's IMD group, held a dinner meeting at Stouffer's Restaurant April 20. The guest speaker was Prof. Alexander R. Troiano, head of the Dept. of Metallurgical Engineering at Case Institute of Technology. He enlarged upon his ASM Campbell Lecture of 1959 to include the effects of hydrogen and other interstitials in fcc and bcc alloys. Delayed failure and strain aging were described and their inter-relationship discussed. Prof. Troiano's work in fields of solid-state transformations, heat treatment of steels and nonferrous alloys, and gases in metals is well known.

BASIC RESEARCH IN PHYSICAL METALLURGY

Outstanding opportunity for physical metallurgist with advanced degree and some research experience in alloy steel, plasticity, and transformations. To work with group of top-flight scientists in areas of deformation and fracture mechanisms in high-strength steels and other alloys, fine structure studies involving transmission-electron microscopy, diffraction, microprobe, etc., within research scope. Progressive research organization in Pittsburgh area with substantial professional growth potential. Excellent employee benefits program; salary commensurate with background and experience.

Send complete resume, including salary requirements to BOX 2-JM.

DEVELOPMENT ENGINEER

Preferably with operating experience, capable initiating, developing, supervising metallurgical, chemical and mechanical processes, has opportunity advancement in medium size non-ferrous smelting organization, attractive Southwest city with many facilities. Age 35-50 and considerable range educational and professional background acceptable. Relocation expenses and agency fees reimbursed. Salary depends on experience and capability. Box 4-JM.

PHYSICAL METALLURGIST

For research and development in aluminum alloys and primary metal processing, with good education and background in basic principles and theory, and wanting to apply research to solution of industrial problems, preferably with advanced degree in Physical Metallurgy.

Write: Dr. M. C. Fetzer
Dept. of Metallurgical Research
KAISER ALUMINUM AND CHEMICAL CORPORATION
Spokane 69, Washington

RESEARCH METALLURGIST

Approximately ten years experience in alloy development and materials application desired. New well-equipped laboratory thirty miles from Philadelphia. Liberal fringe benefits.

Answer Box 3-JM.

CHEMICAL ENGINEER

Capable of designing and operating pilot plants and doing process development experimental work on new methods in extractive metallurgy to work at Metallurgical Laboratories of our Mineral Division near Denver, Colorado. Must be versatile, practical engineer able to make estimates of capital and operating costs of proposed processes and help with engineering design. B.S. in Chemical or Metallurgical Engineering with five to ten years experience in minerals milling or inorganic chemical process. Send resume, photograph and approximate salary requirements to Wayne Hazen, Kerr-McGee Oil Industries, Inc., Route 1, Box 569, Golden, Colorado.

THE NEW BB POWERMET PRESS

FOR THE MOST RAPID MOUNTING OF METALLURGICAL SAMPLES

- PUSH BUTTON CONTROLLED
- POWER OPERATED
- SELF CONTAINED HYDRAULIC SYSTEM
- CONTROLLED MOLDING PRESSURE
- USE PREMOLDS OR POWDER
- BAKELITE OR TRANSOPTIC MOUNTS
- PRODUCES 1", 1¼", or 1½" MOUNTS
- BAYONET TYPE MOLDS
- THERMOSTATICALLY CONTROLLED HEATERS
- QUALITY COMPONENTS USED
- CONFORMS TO J.I.C. STANDARDS

Buehler Ltd.

METALLURGICAL APPARATUS

2120 GREENWOOD ST., EVANSTON, ILLINOIS, U.S.A.

education

Mineral Industries Building

Laboratory facilities in both physical and process metallurgy courses will be improved when the Dept. of Metallurgy at South Dakota School of Mines and Technology moves into the new Mineral Industries Building. Occupation of the new building will also result in strengthening of the metallurgical requirements for the B.S. degree in Metallurgical Engineering.

The principal undergraduate laboratories will consist of six integrated work areas. These include an ore preparation laboratory, the pilot mill, and the mineral dressing laboratory. The pilot mill, with 20 ft head room and a bridge crane that serves the entire floor area, is designed to permit flexible arrangements of equipment so that flow sheets for student laboratory experiments and research projects and industry-sponsored projects may be set up in accordance with the particular requirements of any project.

The metallography laboratory has three metallograph booths with individual film development dark rooms for each, a separate dark room for photographic printing and enlarging, an *isolation* room for dry grinding, and the main laboratory area for polishing, etching, and bench microscopy.

The mechanical testing laboratory will provide testing facilities for hardness, tensile strength, impact strength, creep, and fatigue.

Electron Microscope

Stevens Institute of Technolgy, Hoboken, N. J., has acquired one of the world's most powerful electron microscopes which will enable metallurgists to study the smallest objects ever seen by man—molecules about 30 trillionths of an in. in size.

The new instrument is the fourth and highest-powered electron microscope to be added to the school's Electron Microscopy Laboratory. It will enable Stevens metallurgists to observe directly the building blocks of materials. Such studies provide information on the fundamental properties of solids and can lead to a better understanding of their behavior under operating conditions.

The new unit will be used initially to study thin films on electroplated metals.

Materials Conference

The First International University of California Materials Conference devoted to *The Impact of Transmission Electron Microscopy on Theories of the Strength of Crystals* will meet in Berkeley, Calif, July 5-8.

The meeting is sponsored by the Inorganic Materials Research div. of Lawrence Radiation Laboratory, US Atomic Energy Commission, in cooperation with the University of California Extension and the school's Dept. of Mineral Technology.

Further information may be obtained from the University Extension, University of California, Berkeley 4, Calif.

Engineering Societies Personnel Service Inc.

(Agency)

Under the auspices of the Four Founder Engineering Societies and affiliated with other renowned Engineering Societies, ESPS offers many years of placement experience in addition to world-wide contacts.

New York
8 W. 40th St.

Chicago
29 E. Madison St.

San Francisco
57 Post St.

Change of Address

▼To be sure that you receive your publications and correspondence promptly, please fill in the form below and send it to **The Metallurgical Society of AIME, 29 W. 39th St., New York 18, N.Y.**

Name _____

Old Mailing Address _____

_____

_____

New Mailing Address _____

_____

_____

Personals Form

▼**Personals:** Please list below your former company and title and your new title and company (or new work) for use in JOURNAL OF METALS. (Copy deadline for personals items is six weeks before date of issue.)

Former Company _____

Former Title _____ Length of Time There _____

New Company _____

New Company Address _____ Date of Change _____

New Title _____

Any recent activity that would be of interest to members:

_____

_____

_____

PROPOSAL FOR AIME MEMBERSHIP

I consider the following person to be qualified for membership and request that a membership kit be mailed to him:

Name of Prospective Member:

_____

Address

_____

_____

_____

Name of AIME Member:

_____

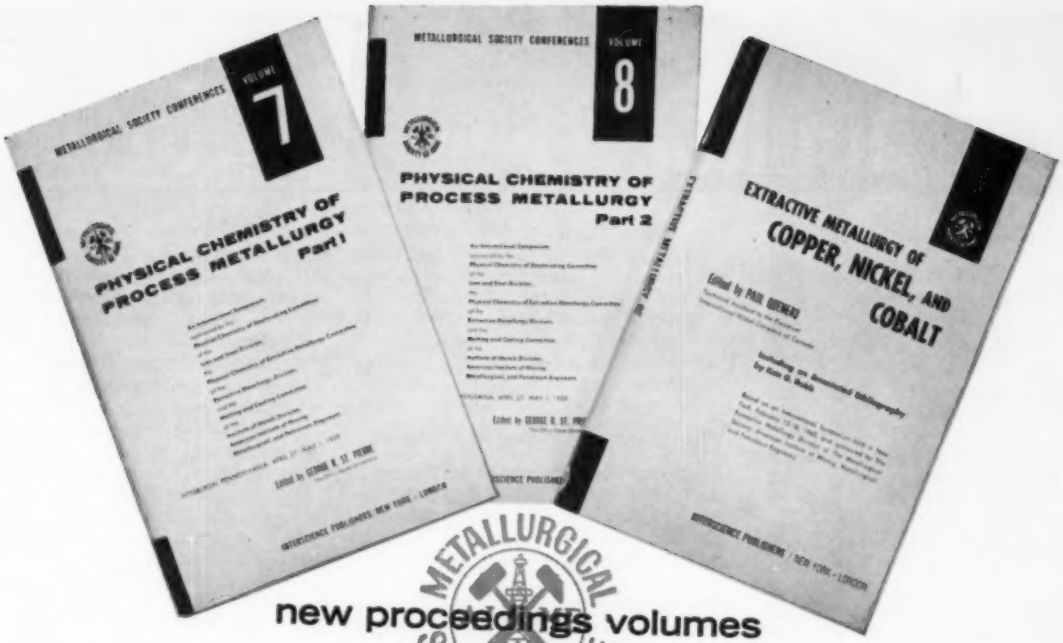
Address

_____

_____

_____

JM


METALLURGICAL SOCIETY CONFERENCES
VOLUME 7
PHYSICAL CHEMISTRY OF PROCESS METALLURGY Part I
METALLURGICAL SOCIETY CONFERENCES
VOLUME 8
PHYSICAL CHEMISTRY OF PROCESS METALLURGY Part 2
EXTRACTIVE METALLURGY OF COPPER, NICKEL, AND COBALT

new proceedings volumes

Physical Chemistry of Process Metallurgy

IN TWO PARTS

volumes 7 and 8 of Metallurgical Society Conferences

Sponsored by the Physical Chemistry of Steelmaking Committee of the Iron and Steel Division, the Physical Chemistry of Extractive Metallurgy Committee of the Extractive Metallurgy Division, and the Melting and Casting Committee of the Institute of Metals Division, The Metallurgical Society, and the Pittsburgh Section of AIME. Pittsburgh, April 27-30, 1959

edited by **GEORGE R. ST. PIERRE**

CONTENTS *(Showing Section titles only)*

Part I

(35 papers)

Physical Chemistry of Metallurgical Phases — Physical Chemistry of Oxide Phases — Thermodynamics of Metals — The Nature and Structure of Liquid Metals — Transport and Mixing — Solubility and Phase Equilibria in Metals Systems

Volume 7, Metallurgical Society Conferences

May, 658 pages **Members: $18.00, Nonmembers: $22.50**

Part II

(32 papers)

Process Reaction Rates and Mechanisms — Solidification of Metals — The Properties of Halide and Sulfide Melts — Industrial Applications of Principles — Desulfurization in the Steel Plant — Hydro- and Electro-Metallurgy — Process Control and Statistical Methods

Volume 8, Metallurgical Society Conferences

May, 744 pages **Members: $20.00, Nonmembers: $25.00**

Extractive Metallurgy of Copper, Nickel, and Cobalt

Based on an International Symposium sponsored by the Extractive Metallurgy Division of The Metallurgy Society of AIME; New York, February 15-18, 1960

edited by **PAUL QUENEAU** including an Annotated Bibliography by **Ken G. Robb**

CONTENTS ***(Showing only Session titles: A total of 24 papers were given, each followed by discussion.)***

General — Fuel-Fired Smelting and Converting — Electric Furnace Smelting — Atmospheric and Elevated Pressure Leaching — Refining — Bibliography

May, approx. 650 pages **Members: $18.00, Nonmembers: $22.50**

Response of Metals to High Velocity Deformation

Volume 9 of Metallurgical Society Conferences

Sponsored by the Physical Metallurgy Committee, Institute of Metals Division, The Metallurgical Society of AIME, Estes Park, Colorado, July 11-12, 1960

edited by P. G. SHEWMON and V. F. ZACKAY

CONTENTS

High Velocity Deformation (6 papers)—Shock Phenomena in Metals (10 papers)

May, 492 pages, about $18.00

A complete listing of forthcoming and previously published volumes is available from The Metallurgical Society or Interscience Publishers upon request.

Members of AIME are entitled to the Special AIME members' Price (twenty per cent discount from the list price) when purchasing the volumes described here. Orders should be directed to The Metallurgical Society of AIME. (N. B. Registrants at any of the conferences covered in the Metallurgical Society Conferences series receive a copy of the Proceedings as part of their registration fee.)

published for The Metallurgical Society of AIME by INTERSCIENCE PUBLISHERS, 250 Fifth Ave., N.Y. 1

books ANNOUNCEMENTS AND REVIEWS

Books that are marked (•) may be ordered through AIME. Address Irene K. Sharp, AIME Book Dept., 29 W. 39 St., New York 18, N. Y. A discount is given whenever it is possible.

Continuous Casting of Steel

Continuous Casting of Steel, by M. C. Boichenko, Butterworth, Inc., 216 pp., $9.50, 1961 (English Language Edition). *Reviewed by M. Tenenbaum, Inland Steel Co.* •

The Boichenko review of the *Continuous Casting of Steel* was first published in Moscow in 1957. Accordingly, the book describes the status of continuous casting as it existed about five years ago. It does not reflect the impressive developments that have been made and the installations that have been put into operation in recent years. Furthermore, it does not recognize the large commercial plants that are approaching completion in Europe and Asia.

The book describes the many continuous casting schemes that have been proposed and points out the problems that have been encountered in trying to cast liquid metal in the various processes. The characteristics of some nonferrous metals such as copper, aluminum, magnesium, zinc, lead, and tin that have made them more amenable to continuous casting are explained. The author extracts many fundamental treatises that describe the solidification and heat extraction phenomena occurring in continuous casting.

The various casting plants outside of Russia that are included in the text have been described in technical publications that have been readily available to JOURNAL OF METALS readers. On the other hand, it is interesting to note that at the time the Boichenko book was being written there were only two operating continuous casting plants in Russia. One was a pilot unit at the Nova Tula Iron and Steelworks, teeming from a 10-ton ladle. This machine had cast about 8000 tons of steel between its installation date and 1956. The second Russian continuous casting plant in operation at that time was located at the Krasnoe Sarmovo Works. This is a twin stranded machine casting 7 x 16½ in. slabs at rates of 45 to 55 tph. An outstanding characteristic of the Russian installations was the underground location of the main units, which makes it possible to service the machines readily with existing shop cranes.

The text emphasizes the inherent advantages of continuous casting in ensuring high product yields and low internal macrosegregation of critical elements. Some cost data are also submitted but these do not appear significant since major adjustments would have to be made to fit the conditions existing in other steelworks, and in other countries.

Progress in Powder Metallurgy

Progress in Powder Metallurgy, published by Metal Powder Industries Federation, New York, 250 pp., $10.00, 1960. *Reviewed by Harold* Hirsch, General Electric Co. •

This is a bound collection of the papers presented at the 16th annual meeting of the Federation held in April, 1960. The table of contents follows:

1) *An Investigation of Ultrasonic Inspection Methods for Sintered Powder Metallurgy Components*—E. H. Abbe, R. D. Korytoski: Springfield Armory.
2) *Machinability of Sintered Iron*—R. S. Jamison, E. Geijer: Hoeganaes Sponge Iron Corp.
3) *A Basis for Non-Destructive Testing of Cemented Carbides*—W. O. Woods: Watertown Arsenal.
4) *Process Controls for Quality and Quantity in Powder Metallurgy*—W. R. Anderson: The Maytag Co.
5) *Checking Density Variations in Powdered Metallurgy Parts by Means of Eddy Currents*—R. H. Kenton: Magnaflux Corp.
6) *The Effect of Powder Particle Size Distribution on the Sintering of Molybdenum*—A. R. Poster: Sylvania Electric Products Inc.; H. H. Hausner: Consulting Engineer.
7) *Chic Sale Looks at Powder Metallurgy*—*W. R. Toeplitz*: Bound Brook Oil-Less Bearing Co.
8) *Heat Treatable Steel-Bonded Carbides*—J. L. Ellis: Sintercast div. of Chromalloy Corp., E. Gregory: Air Reduction Co., Inc., formerly with Sintercast; M. Epner: Sintercast.
9) *Sintered Nickel Steels—The Path to Improved Properties*—W. V. Knopp: S-K-C Research Associates.
10) *A Look at Dispersion Strengthening by Powder Metallurgy Methods*—N. J. Grant: Massachusetts Institute of Technology.
11) *Application of Stainless Steel Powder Metallurgy*—W. L. Batten: Vanadium-Alloys Steel Co.
12) *Application Engineering Applied to Powder Metallurgy Parts*—R. B. Thomson: The United States Graphite Co.
13) *Low Temperature Impact Strength of Sintered Steels*—L. d'A. Menezes: Picatinny Arsenal.
14) *Aircraft Superalloys by Powder Metallurgy*—M. W. Toaz, G. F. Davies, R. D. Johnson: Clevite Corp.
15) *The Sintering and Alloying Behaviour of Nickel-Coated Metal Powders*—J. A. Lund: University of British Columbia; T. Krantz, V. N. Mackiw: Sherritt Gordon Mines Ltd.
16) *The Outlook for Metal Powders and Powder Metallurgy*—K. H. Roll: Metal Powder Industries Federation.
17) *The Testing of Magnetic Powders for Electronic Core Applications*—T. A. Dunton: The Mond Nickel Co. Ltd.
18) *Contribution to the Evaluation and Application of Magnetic Materials*—J. A. Roberts, G. Ludewig: General Aniline and Film Corp.
19) *An Equipment for Measuring the Temperature Coefficient of Permeability of Powder Cores*—T. A. Dunton: The Mond Nickel Co., Ltd.

The title for these proceedings was well chosen for most of the papers represent progress reports and general thinking about the field of powder metallurgy. There was no central core or theme for the conference, although nearly half of the articles are related in some manner to evaluation, inspection, and quality control of metal powder parts and another third were generally devoted to developments in materials and processes.

The Federation's meetings offer the powder metallurgist an opportunity to introduce a new concept, a partially completed survey or study, on interesting comments and appraisal of the field. Several of the papers in this volume describe only the initial stages of an investigation and some raise more questions than they answer. Many of the papers (in particular 2, 3, 6, 8, 9, 11, 13) offer engineering data on a variety of systems and would be particularly useful to those working with the specific materials covered.

(Continued on next page)

Some interesting new possibilities and techniques are presented in the very well organized work of Knopp on nickel additions to iron (9), the production of superalloys from powders by Toaz, Davies, and Johnson (14), and the interesting technique for producing nickel alloys (and presumably, cobalt alloys) by chemical coating the alloying phases with nickel (15).

The two appealing non-destructive testing methods, ultrasonics (1) and eddy current (6) measurements require much more study to be even certain whether they will be of value except for the simplest of shapes. On the basis of the papers presented, the ultrasonic technique has received much more attention than the use of eddy currents.

The papers by Anderson (4), Thomson (12) and Toeplitz (7) present different but valuable aspects of how the powder metallurgist and parts producers can intelligently further the quality and status of the industry and deserve attention.

The three papers (17, 18, 19) presented in a special session are of definite value to the producer and user of electronic cores. Grant does a fine job of summarizing the status of dispersion strengthening systems (10). However, this technique may not be as satisfactory as indicated by the author if the recent observation of dispersed particle coalescence reported by Lenel and co-workers at the 1960 International Conference in New York is a widespread phenomena.

Kempton Roll, executive secretary of the Federation, looks at the growth of the industry as measured by the sales of iron and copper powders, and offers some reasons for this growth.

In general, the proceedings contain something of interest to most powder metallurgists and while, like most other proceedings, it isn't a *must* for a personal library on the subject, it should be perused by all powder metallurgists.

★ ★ ★

Design Information on PH 15-7 Mo Stainless Steel for Aircraft and Missiles, by R. J. Favor, O. L. Deal, and W. P. Achbach, DMIC Report 135, 9 pp., no price quoted, 1960—This report contains current information on the PH 15-7 Mo stainless steel alloy. A brief account of metallurgical and processing information is given to acquaint designers with what may be new terminology common to the expanding use of ferrous-base precipitation-hardenable materials of this general type. Tentative design-allowable strengths are contained in Appendix A. Appendix B contains plots of substantiating data on which the design allowables are based.

Order PB 151093 from the *Office of Technical Services, Dept. of Defense, Washington 25, D. C.*

NOTICE TO AUTHORS

Make sure that manuscripts are typed double-spaced before submitting them to the JOURNAL OF METALS. Failure to do so results in retyping, chance of error, and needless delay. To facilitate matters, submit papers in duplicate and enclose illustrative material such as drawings and glossy photos at the same time. Such illustrations should be suitable for reproduction.

NEW 8th EDITION

IS BIGGER THAN EVER

The new ASM Metals Handbook is the most complete guide to the properties and selection of metals. Its 1300 pages are packed with over 8500 illustrations, charts, graphs and tables, more than 2800 definitions, 1500 examples and comparisons for metal applications, and new data compilations on more than 450 alloys.

Highlights of this outstanding reference book include practical articles on the selection and use of carbon and low alloy steels, stainless steels, heat-resisting alloys, and non-ferrous, magnetic, electrical and other special-purpose materials.

Send for your copy today . . . Price $30.00.

Journal of metals
29 West 39th Street
New York 18, N. Y.

Please rush——copies of ASM's Metals Handbook 8th Edition

Name _____

Company _____

Street _____

City _____ Zone _____ State _____

☐ Bill me ☐ Bill Company ☐ Check Enclosed

* U.S. & Canada only. Add $2 for foreign postage.

HI-TEMPERATURE METALS

Tungsten
Molybdenum
Tantalum
and
Others

Rotatable pure tungsten nozzle formed in 3 pieces and welded with pure tungsten rod.

NOW—for the first time

FABRICATED — WELDED — MACHINED

Super-Temp Eng. & Mfg., Inc. now can offer **complete fabrication** of light or heavy sheet of pure tungsten, molybdenum, tantalum-tungsten and other high temperature metals into almost any shape desired for missiles, space and re-entry vehicles.

Super-Temp's ability to successfully weld segmented parts and assemblies of pure tungsten and other high temperature refractory metals opens up a wide **new** area for the design and use of these metals. Complete facilities are available for the custom machining, bonding and flame spraying of the heat sinks and insulations necessary for high temperature package assemblies.

SERVICES

Fabrication — Machining — Die Forming — Spinning — Flame Spraying — Bonding — Engineering — Assemblies

PART APPLICATIONS

Nozzles, Liners, Throat Inserts, Rings, Flanges, Shields, Blast Tubes, Elbows, Venturi Shapes, Cones. Flame Barriers, Structure Applications and Others.

Super-Temp Eng. & Mfg., Inc.

2024 W. 15th St., Long Beach 13, Calif. **Phones—HEmlock 6-9236 . . . SPruce 5-1600**

personals

Robert Barrow, chief metallurgist, Consolidated · Vacuum Corp., has been elected chairman of the local chapter of American Society for Metals in Rochester, N. Y.

Rixford A. Beals, formerly Editorial Director of MINING ENGINEERING, has been named manager of the Commercial & Industrial div. of the National Better Heating-Cooling Council in New York.

William F. Berry and **Russell R. Dutcher** of Pennsylvania State University, and **A. H. Brisse** of U.S. Steel Corp., have received the American Iron and Steel Institute's Regional Technical Meeting Award in the field of research for their paper *Coal and Coal Seam Composition as Related to Preparation and Carbonization.*

Colin Campbell, business manager of the Society of Exploration Geophysicists, has been elected vice president of the Council of Engineering Society Secretaries.

Roman Chelminski has been admitted to partnership by Singmaster & Breyer, New York chemical process and metallurgical engineers. He joined the firm in 1959 after spending 12 years as a senior partner of Knowles Associates.

Harry Czyzewski, manager of Metallurgical Engineers, Inc., has retired as president of the Consulting Engineers Association of Oregon.

Lawrence S. Darken, associate director, research laboratory, U.S. Steel Corp., has been elected to the National Academy of Sciences. Members are elected on the basis of their distinguished and continued achievements in original research.

Frank H. Driggs has been elected chairman of the board of Fansteel Metallurgical Corp. Dr. Driggs was formerly the company's president and chief administrator.

Ernst M. Goldstein has been appointed to the research and development staff of Shieldalloy Corp., of Newfield, N. J. He was formerly senior research chemist with Metal & Thermit Corp.

S. C. Guillan has retired as secretary of The Institute of Metals, London.

E. L. Harmon is now supervisor, physical metallurgy, at the research laboratories of Ford Motor Co.'s Aeronutronic div., in Newport Beach, Calif. He was previously with the Jet Propulsion Laboratories in Pasadena.

F. R. Hensel, vice president, engineering, of P. R. Mallory & Co. Inc., has retired from the company, with which he has been associated for 26 years.

Lytton A. Kendall, Jr., has been named application engineer in the processing machinery department of Allis-Chalmers Manufacturing Co. He recently completed the company's training course for graduate engineers.

J. Lindsay Johnson has been named vice president of Interlake Iron Corp. He was formerly director of planning and development.

Thomas I. Moore has been elected vice president and manager of the Monsanto Electrolytic div. of American Zinc Co. of Illinois.

Rolph A. Person and **Robert T. Sanden** have been promoted to technical supervisors in the metallurgical engineering group of Union Carbide Metals Co. Dr. Person was formerly in engineering services and Mr. Sanden was in the product and process development department.

Gilbert R. Rothschild has been appointed assistant director, metallurgical development, heading a new division of the Central Research Laboratories of Air Reducton Co. Inc.

Merrill A. Scheil, director of metallurgical research for A. O. Smith Corp., has received a citation from the University of Wisconsin for "outstanding accomplishments as engineer, author, and administrator."

R. W. Simon has been appointed vice president, metallurgy, of U.S. Steel Corp., replacing **L. J. Rohl** who retired April 30. Mr. Simon was formerly chief metallurgical engineer, operations—steel.

David Turnbull of the metallurgy and ceramics research department of General Electric Research Laboratory participated in the International Materials Science Symposium which was held in Paris in May. Dr. Turnbull was selected to attend the conference by the Advisory Group for Aeronautical Research and Development of the North Atlantic Treaty Organization. He presented a paper on *Thermodynamics and Kinetics of Phase Changes in Solids.*

John Robert Van Pelt, president of Michigan College of Mining and Technology, has been elected to the board of directors of Copper Range Co.

Karl M. Weigert is now on the staff of Pennsylvania State University where he is giving courses in metal working and joining. He is also devoting time to research and investigations for industry and government agencies. He was formerly senior research metallurgist with the Curtiss-Wright Research div.

J. H. Westbrook of the General Electric Research Laboratory is one of four U.S. scientists selected by the Electrochemical Society to visit research institutions in the Soviet Union. He is a member of the Ceramics Studies Section of the laboratory's Metallurgy and Ceramics Research dept.

James L. Wyatt has been named vice president for development at the Armour Research Foundation of Illinois Institute of Technology. He was formerly with Booz-Allen and Hamilton, management consultants.

STEEL MILL ENGINEER

for position as Mill Manager in Argentina. Plant situated within 50 miles from Buenos Aires. Require graduate rolling mill engineer with at least 5 years experience in all aspects of structural and merchant bar mill and with good managerial abilities. Knowledge of the Spanish language preferred. Applicant must be fully qualified to supervise and operate existing facilities as well as to develop modernization and expansion program. Box 5-JM.

UNIVERSITY OF BRITISH COLUMBIA

Invites applications for the post of

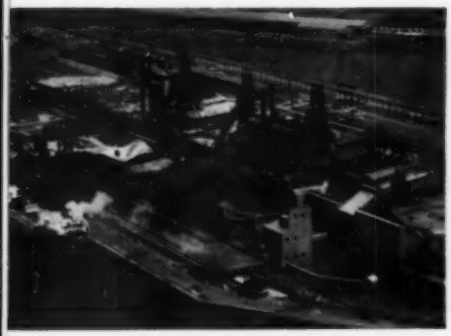
Assistant Professor of Metallurgy

Attractive post in expanding Department for a man in the field of physical metallurgy, metal physics, materials science. Applicants should have Ph.D. or equivalent and subsequent academic, industrial, or research experience. Duties comprise undergraduate teaching, supervision of graduate work and participation in research at professional level. Opening available September 1, 1961. Salary $7,000 per year plus generous benefits. Applications should be submitted by June 30th next to Professor F. A. Forward, Head of the Department, University of British Columbia, Vancouver 8, B.C.

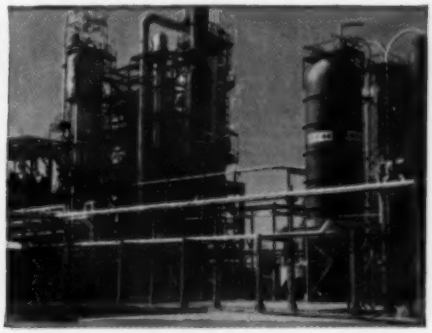
STEEL MILL MANAGER

for plant situated in Great Britain (Midlands). Experienced in milling and rolling of stainless steel. Applicant should be qualified to modify existing blooming and billet mill and to install and operate facilities for rolling slabs and bars. Box 6-JM.

HERE'S HOW McKEE-WKE ENGINEERS CAN WORK FOR YOU



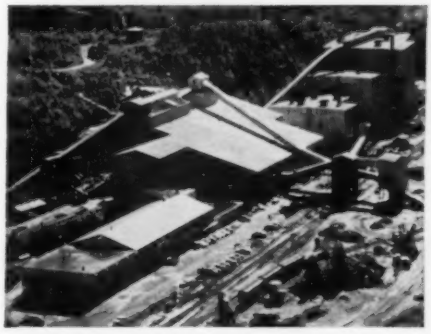
BLAST FURNACES Sound planning and experienced construction know-how put these three furnaces and the sintering plant at an Eastern Pennsylvania plant in production on scheduled dates. McKee engineering services help make your new-plant investment start earning profits at the earliest possible date.



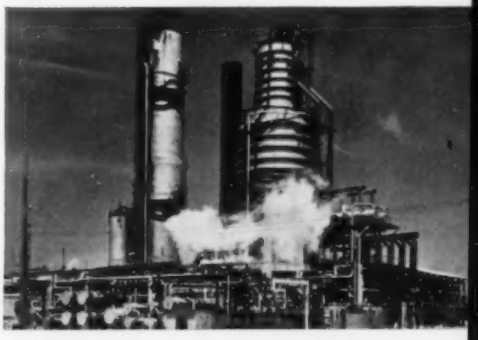
PETROLEUM PROCESSING This new fluid catalytic cracker is a typical result of McKee services at work. A single turn-key contract converted a bare construction site into a producing plant that is delivering specified performance. Knowledge, experience and ability, instantly available, did the job.

OPEN-HEARTH SHOP One of a wide variety of plants McKee designs and builds for the steel industry, this open-hearth shop is producing efficiently in the Chicago District. Our intimate knowledge of steel making, from mine to finished steel, makes McKee-WKE services work more effectively for you.

COPPER SMELTING In non-ferrous metals your first call for engineering and construction should be for McKee-WKE services. This large, fully integrated plant shows you why. Newest copper smelter in America, it was designed, and completed ahead of schedule by WKE. Here again, you can reach into a pool of engineering talent devoted to a specialized field.

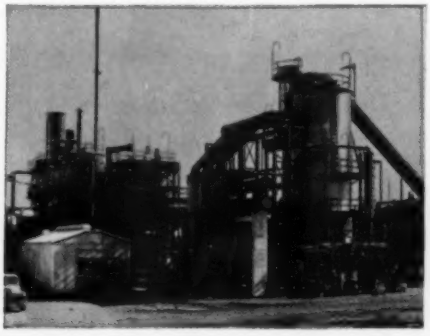


ORE BENEFICIATION WKE leadership in ore beneficiation is combined with McKee leadership in pelletizing. This 650,000-ton pelletizing plant, designed and built by McKee, is fed by an iron ore concentrator designed and built by WKE. The specialized fund of McKee-WKE knowledge that produced them can give you superior results, too.



CRUDE OIL DISTILLATION High capacity and almost automatic operation make this combination atmospheric and vacuum unit an outstanding example of McKee design and construction. Capable of processing upward of 150,000 barrels per stream day, it is, so far as we know, the world's largest crude unit — proof that the industry entrusts the big ones to McKee.

URANIUM ORE CONCENTRATION Here is another project which illustrates the broad scope of our services. WKE engineers have served this industry since its commercial birth with complete design and construction of 10 of the 25 U.S. uranium ore concentration plants, and participation on many of the other fifteen. WKE's thorough knowledge of ores and minerals, intelligently applied, can save you time and money.



CHEMICAL PROCESSING This modern sulfuric acid plant joins the ranks of McKee-WKE plants designed to produce sulfuric acid, nitric acid, hydrazine, urea, polyvinyl chloride, chemicals from coal and similar products. Our broad, diversified knowledge in petroleum, petrochemicals, metals and minerals helps McKee and Western Knapp engineers build more efficient, more economical chemical plants for your company.

AGGREGATE PROCESSING This $5,000,000 aggregate processing plant shows how experience gained in one area of industry is used to advantage in another. The new plant employs certain methods originally developed by Western Knapp engineers for the mining and minerals producing industries. The ability to apply wide knowledge from many fields is another reason McKee-WKE services should be working for you.

THE FULL STORY OF HOW McKEE AND WKE CAN WORK FOR YOU ON YOUR SPECIFIC PROJECT IS YOURS FOR THE ASKING. A CALL TO OUR NEAREST OFFICE WILL BRING YOU A PROMPT RESPONSE

THE McKEE ORGANIZATION **ARTHUR G. McKEE & COMPANY**, 2300 Chester Ave., Cleveland 1, Ohio. *Offices:* New York; Union, N. J.; Washington, D. C.; Houston, Texas. *Subsidiaries:* Toronto and Montreal, Canada; Mexico City, Mexico; Sao Paulo, Brazil; Buenos Aires, Argentina; McKee Head Wrightson, London. **WESTERN KNAPP ENGINEERING CO.** 650 Fifth St., San Francisco 7, Calif. *Offices:* New York; Chicago; Hibbing, Minn.

INTERNATIONAL ENGINEERING AND CONSTRUCTION SERVICES

High Temperature
RESEARCH FURNACE*

*PATENTED U. S. A.

High Temperature Operation —
Up to 5100°F for intermittent use, up to 4800°F for continuous operation.

Extremely Compact —
8" high x 4" diameter working volume contained within a 20" x 10½" unit. Also available, 15" high x 12" diameter working volume contained within a 30½" x 22" unit.

Controlled Atmosphere — Inert gas protects charge and furnace element.

Water-Cooled — Circulation through electrodes, coverplates and outer shell.

Easy Furnace Access —
Removable top and bottom covers, with hearth lift mechanism for bottom loading.

Unrestricted Viewing —
Inert gas is directed against side and top sight ports to scavenge atmosphere.

Unusually compact and economical laboratory furnaces meet the severe requirements of melting and sintering materials in excess of 4500°F. Curtiss-Wright Research Furnaces feature a specially designed cylindrical graphite resistance element surrounded by a graphite radiation barrier, carbon insulation and aluminum outer shell; mounted on a vertical supporting column for easy access. Equipment and instrumentation is available for any degree of semi-automatic or automatic control.

Systems Engineering Services available

Phone SWinburne 9-0500 or write:

CURTISS WRIGHT
CORPORATION

Princeton Division • Princeton, N. J.

NEW BULLETIN

A new bi-weekly bulletin of "Engineers Available" is now being published by the Engineering Societies Personnel Service, Inc. Distributed free of charge, the bulletin contains synopses of the experience of engineers who have registered with the Service and are seeking a new position.

Any employer interested in receiving the bulletin should so advise E.S.P.S. at 8 W. 40th St., New York 18, N.Y., and your name will be placed on the mailing list. Any engineer who is registered with the Service or wishes to register is entitled to a 35-word notice in the bulletin. Write to the New York office for forms. Your qualifications will be brought to the attention of employers on our mailing list without revealing your identity.

It is planned to extend the publication to the midwestern and western offices in the near future.

when you need

LITERATURE SEARCHES
TRANSLATIONS
BOOKS ON LOAN
PHOTOPRINTS
MICROFILM

why not contact . . .

The Engineering Societies Library
33 West 39th Street
New York 18, N. Y.

Please send me information pamphlet on services available, how air mail can expedite them, and their cost.

Name.....

Street.....

City.....

State.....

IMD Special Report Series Number Eight

METALLURGICAL SOCIETY OF AIME

ANGLES

Between Planes in Cubic Crystals

By R. J. Peavler and J. L. Lenusky

This small but valuable 28-page booklet contains tables of interplanar angles in the cubic system up to {554}. Calculated on a digital computer by members of the Crystallographic Group at Westinghouse, the values were checked carefully to prevent error in transcription. Typographical errors were eliminated by reproducing the original tables. Invaluable for orientation work in many phases of physical and X-ray metallurgy. Author R. J. Peavler is a crystallographer in the Crystallographic Group of the Materials Engineering Departments, Westinghouse Electric Corp. J. N. Lenusky is a former laboratory assistant in the Crystallographic Group. This report is priced at $1.50 to non-members, $1.00 to AIME members.

AIME, 29 W. 39 St., N. Y. 18, N. Y.

Please send me a copy:

Angles Between Planes in Cubic Crystals

Name .....

.....

Address .....

City .....

(Nonmember Foreign Order, Add 50¢ for Mailing)

Technical Conference

Metallurgy of Semiconductor Materials

FINAL PROGRAM

Ambassador Hotel, Los Angeles — August 30-September 1, 1961

Sponsored by

Semiconductors Committee, Institute of Metals Division of
The Metallurgical Society, and
Southern California Section, AIME

Locations

Registration	South Lobby
Sessions and Dinner	Embassy Room
Conference Headquarters	Garden Room

TUESDAY, AUGUST 29

7:30 to 10:00 pm — Conference Registration

WEDNESDAY, AUGUST 30

Thermionic Energy Conversion Materials

9:00 am to 12:30 pm—Session I

J. J. Connelly, Office of Naval Research, Chairman

Opening Remarks:
H. E. Bridgers, Chairman, IMD Semiconductors Committee

Considerations in the Selection of Materials for Thermionic Converter Components:
P. Goodman, Allied Research Associates, Inc.

High Temperature Properties of Thermionic Emitters:
M. C. Bowman, Los Alamos Scientific Laboratory

Materials for Direct Conversion of Heat to Electrical Power by Thermionic Emission:
L. S. Richardson, A. E. Fein, M. Gottlieb, G. Kemeny, and *R. Zollweg*, Westinghouse Research Laboratories.

Some Physico-Chemical Criteria for the Selection of Carbides as Thermionic Emitters:
L. Yang, F. D. Carpenter, A. F. Weinberg and *R. G. Hudson*, General Atomic Laboratories

High Temperature Metallic Cathode Problems:
N. R. Rasor, Atomics International

Structural and Emitter Materials for Nuclear Thermionic Converters:
P. Stephas and *L. N. Grossman*, General Electric Company, Vallecitos Atomic Laboratory

Thermoelectric Energy Conversion Materials

2:00 to 5:00 pm—Session II

J. Blair, Massachusetts Institute of Technology, Chairman

Narrow Band Semiconductors as High Temperature Thermoelectric Elements:
R. R. Heikes, R. C. Miller, and *A. E. Fein*, Westinghouse Research Laboratories

Rare Earth Sulphides as High Temperature Thermoelectric Materials:
P. Miller, General Atomic Laboratories

Preparation and Properties of Some Rare Earth Semiconductors:
F. L. Carter, Westinghouse Research Laboratories

Annual Conference Dinner

Wednesday, August 30

Reception:	6:30 pm
Dinner:	7:30 pm
Speaker:	To be announced
Ticket Price:	$7.00

Registrants are advised to purchase tickets with advance registration and in no case later than **12:00 noon on Wednesday, August 30,** at which time it will be necessary to suspend ticket sales in order to determine a firm attendance figure.

Thermoelectric Behavior of the Semiconducting System $Cu_xAg_{1-x}InTe_2$:
S. M. Zalar, Raytheon Company

Preparation and Properties of Silver-Antimony-Tellurium Alloys for Thermoelectric Power Generation:
R. Johnson and *J. Brown*, Westinghouse

Extrusion of Bi_2Te_3 Alloys:
J. B. Schroeder and *S. F. Nester*, Ohio Semiconductors

Effects of Heavy Deformation and Annealing on Thermoelectric Properties of Semiconductor Compounds:
J. M. Schultz, J. P. McHugh, and *W. A. Tiller*, Westinghouse Research Laboratories

THURSDAY, AUGUST 31

Materials and Techniques for Microelectronics I

9:00 am to 12:30 pm—Session III

C. E. Ryan, AFCRL, Chairman, and
R. Cornelissen, AFCRL, Co-Chairman

Surface Passivation Techniques in Microelectronics:
S. S. Flaschen, Motorola, Inc.

Status of Vapor Growth in Semiconductor Technology:
R. Glang and *E. S. Wajda*, IBM Laboratories

The Role of Imperfections in Semiconductor Devices:
W. Shockley and *A. Goetzberger*, Shockley Transistor

Technology of Integrated Semiconductor Devices and Circuits:
J. M. Goldey, Bell Telephone Laboratories

Imperfections in Germanium and Silicon Epitaxial Films:
T. B. Light, Bell Telephone Laboratories

Materials and Techniques for Microelectronics II

2:00 to 5:00 pm—Session IV

D. C. Jillson, General Electric Co., Chairman

Some Factors Affecting the Resistivity of Epitaxially Grown Silicon Layers:
H. Basseches, R. C. Manz, C. O. Thomas, and *S. K. Tung*, Bell Telephone Laboratories

The Influence of Process Parameters on the Growth of Epitaxial Silicon:
S. K. Tung, Bell Telephone Laboratories

Halogen Vapor Transport and Epitaxial Crystal Growth of Intermetallic Compounds and Compound Mixtures:
N. Holonyak, General Electric Co.

Epitaxial Germanium Layers by Cathodic Sputtering:
F. Reizman and *H. Basseches*, Bell Telephone Laboratories

Evaluation Techniques for, & Electrical Properties of Silicon Epitaxial Films:
C. C. Allen and *E. G. Bylander*, Texas Instruments

Transmission Electron Microscopy of Evaporated Germanium Films:
O. Haase, Bell Telephone Laboratories

Doping of Silicon Epitaxial Layers:
W. J. Corrigan, Motorola, Inc.

Texture and Orientation of Evaporated Bismuth Films:
T. P. Turnbull and *E. P. Warekois*, Lincoln Laboratory

FRIDAY, SEPTEMBER 1

Research in Progress in Semiconductors

9:00 am—Session V

M. Tanenbaum, Bell Telephone Laboratories, Chairman

Abstracts received by July 15, 1961 will be considered. Forward submissions to W. V. Wright, Electro-Optical Systems, Inc., 125 N. Vinedo Ave., Pasadena, Calif.

Conference Committee

W. V. Wright	*General and Program Chairman*
C. G. Kirkpatrick	*Arrangements Chairman*
F. P. Burns	*Registration Chairman*
J. V. Houston	*Publicity Chairman*
J. O. McCaldin	*Treasurer*

IMD Semiconductors Committee

H. E. Bridgers	*Chairman*
F. L. Vogel	*Vice-Chairman*
G. E. Brock	*Secretary*
J. B. Schroeder	*Treasurer*
D. C. Jillson	*Past Chairman*

General Information

Registration

Advance registration material will be sent to most persons reading this announcement. If not received by August 1, or if additional copies are required, contact J. O. McCaldin, Treasurer, 1961 Semiconductor Conference, P. O. Box 49892, Los Angeles 49, Calif. Registration fees for the conference, including the Proceedings Volume, are $10 for AIME members, $15 for nonmembers. Non-members who submit applications for membership prior to, or upon, registering are eligible for the member rate of $10. Refunds of $5 will be made to non-members joining during the conference.

Excursions and Vacation Trips

Disneyland, Marineland, and movie studio tours will be available Friday afternoon, September 1, with buses departing from the Ambassador Hotel. Special group vacation trips to Hawaii and Mexico can be arranged in advance for September 1-9, 1961. Fare-saving commercial airline charters from New York to Los Angeles must be arranged early if there is sufficient interest. Additional information on excursions and vacation trips will be included with the pre-registration material.

Proceedings volume

The papers and discussions at the Conference will be published as one of the continuing series of *Metallurgical Society Conferences*, printed by Interscience Publishers, Inc. The volume will be automatically sent registrants without further charge. Every effort will be made to insure prompt publication of the volume to increase its usefulness to registrants.

New Zr process

Zirconium tetrachloride, $ZrCl_4$, with hafnium concentrations of less than 0.01 wt pct can now be produced economically by a process developed by U.S. Industrial Chemicals Co. The new process was announced at the recent 139th National Meeting of the American Chemical Society. High costs of producing reactor-grade metal have limited the use of zirconium thus far; however, this process is said to reduce the costs of reducing $ZrCl_4$ approximately 50 pct and could possibly lead to less expensive zirconium metal.

In the new process, $ZnCl_4$ is selectively reduced by zirconium dichloride to the trichloride state, but the hafnium tetrachloride is not reduced. Since $ZrCl_3$ is nonvolatile and $HfCl_4$ is volatile, they can easily be separated by sublimation. The remaining $ZrCl_3$ is disproportioned a 420° to 550°C to regenerate the $ZrCl_2$ and, after passing through sufficient stages, yields $ZrCl_4$ having less than 0.01 pct hafnium. The zirconium can then be further reduced to zirconium by treatment with sodium or magnesium. The main advantages of the method are that it is not based on solution chemistry as are other methods, and that zirconium tetrachloride can be produced directly.

Powder Zircaloy 2

The Metallurgical Products Dept. of General Electric Co. announced the commercial availability of Zircaloy 2 as produced by a unique powder metallurgy process. It is a modified vacuum hot-pressing technique which also is superior for producing finished or semi-finished shapes of columbium, tantalum, and their carbides. The primary advantage of the new process is the production of finished or semi-finished shapes which require only light machining. Even special shapes can be held to close tolerances.

The new powder alloy meets all nuclear specifications, including the Navy Mil Z nuclear specification. The process also produces material with outstanding physical characteristics. For instance, the density is 6.57 g per cu cm, which is 100 pct of the theoretical value. An additional advantage is that the physical properties of the new material are non-directional.

New Cu process

Start-up of a new mining-leaching-smelting operation at the Mantos Blancos property in Chile has been announced. The process is unique in that it represents the first successful, commercial attempt to leach a combination atacamite-chrysocolla ore. The ore is leached with sulfuric acid, and the cupric chloride is later reduced to insoluble cuprous chloride by sulfur dioxide. Leaching liquid is recycled, and the relatively pure cuprous chloride is mixed with finely-ground coke and limestone and then pelletized. Pellets are melted in a rotating furnace, and a second rotating furnace is used to refine the copper. Treating 3000-tpd of ore, the operation produces 50-tpd of fire-refined copper which is shipped to the European market.

Direct casting process

A machine that directly casts molten steel into slabs of sufficiently large tonnages to operate on a volume basis is being built by the American Shipbuilding Co. using the controlled pressure-pouring process developed by Griffin Wheel Co., a subsidiary of American Steel Foundries. In the process, molten steel is forced from the ladle, through a refractory tube, into a semi-permanent graphite mold. A more detailed description of the process appeared in the September 1960 issue of JOURNAL OF METALS, p. 698.

American Metal Market recently reported that E. Q. Sylvester, American Shipbuilding president, stated that the proposed machine is designed to cast a 25-ft long x 65-in. wide slab, and is confident that the machine will handle 300 tons of molten steel in 30 min. However, officials of American Steel Foundries emphasized the experimental nature of the machine, and declined to be definite until the machine is put into operation at the Bensenville, Ill., laboratory. J. B. Lanterman, president of American Steel Foundries, said that U.S. Steel is working on plans for possibly installing one or more semi-production units, using the Griffin process. He also stated that one or more of the units may be in operation within a year.

Ni and Co powder products

Sherritt-Gordon Mines Ltd. expects to begin shipment of commercial quantities of nickel and cobalt products rolled from powders. The company's powder mill at Fort Saskatchewan, Alberta, Canada, has been working on the development of operating techniques for producing cobalt and nickel strip, rod, and wire. Reportedly, it is now possible to manufacture a number of nickel, cobalt, and copper alloys and composite materials for a variety of commercial applications. According to company sources, the mill is producing products never produced previously. For example, the mill has produced a roll of pure cobalt strip believed to be the largest ever produced.

Coke pellets?

Will the blast furnaces soon be operating with pelletized coke? Agglomeration and pelletizing of limestone and ores is becoming more common, and it appears that pelletized coke may not be too far in the future.

Officials of Consolidated Coal Co. reported that several companies have been working cooperatively to produce a *carbon fuel* for the blast furnace; the most promising shape appears to be a small pellet of about 0.5 in. diam. The theory is that standard size pellets will greatly improve furnace performance and productivity in much the same way that ore and limestone pellets have done. Since the coke pellets would be produced in a fluidized bed type reactor, it would be possible to utilize lower grade coals, rather than the higher-priced metallurgical grade coals now required for the by-product method.

REPORTER

REPORTER

Large-scale RN test

Allegheny-Ludlum Steel Corp. is considering the RN direct iron-ore reduction process for its alloy and special steelmaking operations. The firm, which does not have pig-iron producing facilities, recently revealed that it ran a large-scale melting test in a German plant in cooperation with the R-N Corp. The test reportedly demonstrated that a direct ore-reduction process with a hot-blast cupola could be an alternate route for producing hot metal. Company officials emphasized that they will continue to explore the flexibility and adaptability of the process.

Ferronickel in Brazil

A new 100-tpd ferronickel plant is under construction in Brazil. Using 2 pct Ni ore from the Moro do Nickel mine near Passos, the plant will utilize the process developed by Le Nickel in New Caledonia which was described in the March 1960 issue of JOURNAL OF METALS, p. 202. The Ekektrokemisk furnaces will make use of power from the new project at Ribeiro Prêto. The plant is to be operated by Brasimet, associated with the Hochschild interests.

EB annealing

Temescal Metallurgical Corp. recently announced the development of a fully continuous annealing furnace which uses electron beam heating to process metal sheets in a high vacuum. The new furnace is said to be a major improvement in the production of thin sheet metal in strip form. Until now, all reactive metal strip annealing has been performed in batch operations which are said to be considerably more costly than the new electron beam heating method. Coils of strip unwind and rewind in air at each end of the apparatus, while the strip passes into and out of a high vacuum system. Electron beam heating and other processing steps take place within the high vacuum chamber. The process is expected to find broad application in the processing of reactive metals such as tantalum, columbium, titanium, and zirconium, as well as other metals requiring high vacuum or purified environment during annealing.

Largest continuous casting unit

The largest continuous casting unit in the world is being constructed at Stoke-on-Trent for Shelton Iron & Steel Ltd. The unit will consist of four vertical installations having a total of 13 casting lines and will produce a wide range of billet sizes. Constructed under license of Concast AG of Zurich, the installation will be supplied hot metal by two 45-ton converters. The new unit will make Shelton Iron & Steel the first integrated plant in the UK to use continuous casting for its entire production of semi-finished products.

300,000,000th ton Cu ore

A record output of 300 million tons of copper ore from Branden Copper Co.'s—a subsidiary of Kennecott Copper Corp.—El Teniente mine in Chile was celebrated recently. Representatives of the Chilean government, labor leaders, and officials of the company participated in a brief ceremony held at the entrance to the largest underground copper mine in the world. Although two other mines previously had passed the 300 million ton mark in ore production—the Bingham, Utah, open-pit mine of Kennecott Copper, and the Chuquicamata, Chile, open-pit mine of Anaconda Copper—no other underground copper mine has approached this total.

Soviet LD plants

The Austrian steel firm, VOEST, is reportedly negotiating with the USSR for the construction of two LD steel plants of 3-million ton annual capacity each. It is also reported that discussions relative to the construction by VOEST of an LD steel plant at Galatz in Rumania are now entering into their final phases. A unique feature of the proposed plant is that it will not have blast furnace facilities, but rather will be supplied with Russian pig iron.

The *Financial Times* reported recently that a long-term contract with the USSR has been signed by VOEST for 1962-65. Austria will buy 2.8 million tons of coking coal, 1.3 million tons of iron ore, and 60,000 tons of manganese ore. In return, Austria will export to Russia 580,000 tons of rolled products—mainly sheet. [And the LD plants? Ed]

Kennecott basic research

A basic research program with primary emphasis on solid-state physics of metals will be launched by Kennecott Copper Corp. The announcement was made at a recent annual stockholders' meeting. E. W. Fletcher of the Dept. of Electrical Engineering of MIT has been named director of the program. M. J. Kelly, formerly director of the Bell Telephone Laboratories, will act as consultant. Kennecott has a program of applied research underway at its Salt Lake City laboratory, and at its fabricating subsidiary, Chase Brass & Copper Co., Waterbury, Conn.

TRANSACTIONS
OF THE METALLURGICAL SOCIETY OF AIME

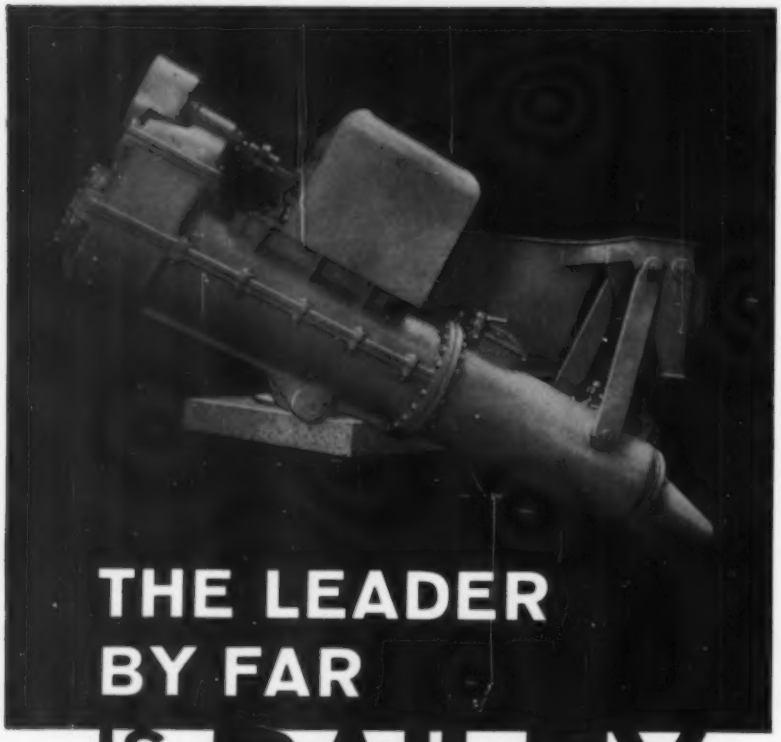
Contents of the June 1961 TRANSACTIONS

The 1961 Institute of Metals Division Lecture. The Liquid State and the Liquid-Solid Transition—David Turnbull 422
Secondary Recrystallization Kinetics in Singly Oriented Silicon Iron—T. V. Philip and R. E. Lenhart 439
The Zirconium-Platinum Alloy System—E. G. Kendall, C. Hays, and R. E. Swift 445
Creep of a Recrystallized Aluminum SAP-Type Alloy—G. S. Ansell and L. V. Lenel 452
Prismatic Glide in Cadmium Crystals—J. J. Gilman 456
Effect of Copper Additions on the Activation Energies for Creep of Aluminum Single Crystals—D. Walton, L. Shepard, and J. E. Dorn 458
Interpretation of the Rolling Texture of Copper—M. N. Parthasarathi and Paul A. Beck 461
Sulfur Equilibria between Gases and Calcium Ferrite Melts—E. T. Turkdogan and L. S. Darken 464
Delay Time in Single Crystals of Aluminum, Zinc, and Iron—I. R. Kramer 474
Thermodynamic Activities in the Fe-Mn-C System—J. F. Butler, C. L. McCabe, and H. W. Paxton 479
A Thermochemical Model of the Blast Furnace—H. N. Lander, H. W. Meyer, and F. D. Delve 485
Penetration of Liquid Bismuth into the Grain Boundaries of a Nickel Alloy—R. F. Cheney, F. G. Hochgraf, and C. W. Spencer 492
Transformation Kinetics in High-Purity Iron and Some Iron Binary Alloys—V. Bharucha, G. A. Mancini, G. W. Powell, and J. W. Spretnak 498
The Structure and Associated Properties of an Age Hardening Copper Alloy—W. D. Robertson, E. G. Grenier, and V. F. Nole 503
Synthetic Inclusions in the FeO-MnO-MnS-SiO_2 System in Equilibrium with Resulfurized Steel—E. N. Silverman 512
Notch Sensitivity of Refractory Metals—A. G. Imgram, F. C. Holden, H. R. Ogden, and R. I. Jaffee 517
Some Thermodynamic Properties of the Cadmium-Copper System—Richard Borg 527
The Solubility of Nitrogen in Solid Iron-Nickel Alloys Near 1000°C—H. A. Wriedt and O. D. Gonzalez 532
Acid Bessemer Oxygen-Steam Process—G. M. Yocom 536
Nucleation Catalysis by Carbon Additions to Magnesium Alloys—V. B. Kurfman 540
Oxygen Potentials and Phase Equilibria in the Fe-Ca-O System—E. T. Turkdogan 546
Hardness Anisotropy in Single Crystal and Polycrystalline Magnesium—M. Schwartz, S. K. Nash, and R. Zeman 554
Diffusion in Gamma Brass—Carl F. Lutz and Robert F. Mehl 561
Dilatometric Investigation of Vacuum-Melted Zircaloy-2—Joseph Intrater 567
Phase Diagram and Thermodynamic Properties of the Thorium-Zinc System—P. Chiotti and K. J. Gill 573
The Gadolinium-Iron System—V. F. Novy, R. C. Vickery, and E. V. Kleber 580
The Gadolinium-Nickel System—V. F. Novy, R. C. Vickery, and E. V. Kleber 585
The Gadolinium-Cobalt System—V. F. Novy, R. C. Vickery, and E. V. Kleber 588
The Thermal Decomposition of Cobalt Sulfate—J. Stuart Warner 591
Development of Copper Base High Strength-Medium Conductivity Alloys Cu-Ti-Sn and Cu-Ti-Sn-Cr—Matti J. Saarivirta 596
Orientation Relationships in the Heterogenous Nucleation of Solid Lead from Liquid Lead—B. E. Sundquist and L. F. Mondolfo 607
A Study of the Growth of Voids in Copper During the Creep Process by Measurement of the Accompanying Change in Density—Raymond C. Boettner and W. D. Robertson 613
The Solubility of Hydrogen in Alpha Iron—M. L. Hill and E. W. Johnson 622
The Melting of Malleable Nickel and Nickel Alloys—C. G. Bieber and R. F. Decker 629
A Study of the Titanium-Nickel System Between Ti_2Ni and TiNi—G. R. Purdy and J. Gordon Parr 636

TECHNICAL NOTES

The Structure of Ti_3Al—A. J. Goldak and J. Gordon Parr 639
Effect of Grain Size on Brittle Fracture in Steel—F. de Kazinczy and W. A. Backofen 640
The Production of Controlled Orientation Bicrystals for Grain Boundary Migration Studies—J. W. Rutter and K. T. Aust 641
The Phase Relationships in the Magnesium-Rich Region of the 335°C Tetrahedron of the Mg-Al-Ca-Zn Phase Diagram—J. B. Clark 643
The Solid Constitution in the Magnesium-Rich Region of the Mg-Ca-Zn Phase Diagram—J. B. Clark 644
Stacking Faults in Platinum—J. Taranto and F. R. Brotzen 645
Observations on the Powdering of Yttrium Hydride—John D. Roach 646
On the Existence of Lower Tantalum Oxides—R. J. Wasilewski 647
Density Anomalies in the Bi_2Te_3-Sb_2Te_3 System—L. R. Testardi and J. R. Wiese 647
Optimum Conditions for Zone Refining—J. D. Harrison and W. A. Tiller 649
Hot Pressing of Lead Spheres—F. E. Westermann and R. G. Carlson 649
Identification of Deformation Twins in a Molybdenum-35 Pct Rhenium Alloy—H. W. Schadler and A. Lawley 650
Corrections 652

IN CLAY GUN PERFORMANCE...



THE LEADER BY FAR IS BAILEY

Extremely accurate and fast positioning, Bailey Clay Guns furnish the high clay pressures (642 to 1150 psi) which are so necessary with the new coke-tar tapping hole mixes now being used on many furnaces. Unique mounting and 3-motor operating system assure quick and reliable positioning in the tapping hole. There are more than 170 Bailey Clay Guns in blast and electric furnace service.

• *Write for bulletin.*

WILLIAM M. Bailey COMPANY
ENGINEERS
LEADERSHIP THROUGH QUALITY
1221 BANKSVILLE ROAD PITTSBURGH 16, PA.

letters to the editor

UK Beryllium

We would like to correct the impression given in the statements, made on pages 115 and 139 of the February 1961 issue of JOURNAL OF METALS, relating to beryllium production in Europe.

Consolidated Zinc Corp. Ltd., has been engaged in the development of the thermal reduction process for the production of beryllium metal since 1949.

Through our United Kingdom subsidiary, Imperial Smelting Corp. Ltd., in an equal association with The Beryllium Corp., Reading, Pa., a new company, Consolidated Beryllium Ltd., was formed in July, 1959, to produce beryllium and beryllium copper alloys. Plants for the production of these metals and alloys are in commercial production in the U. K.

In September 1960, the UK Atomic Energy factory at Milford Haven, Pembrokeshire, was acquired and with it the facilities for processing raw beryl ore to nuclear grade beryllium oxide and the fabrication of beryllium oxide into slip cast shapes and hot-pressed sintered shapes.

Consolidated Beryllium Ltd., is able to provide beryllium in all forms of ingot, swarf (chippings), or powder; beryllium copper master alloys; beryllium oxide and ceramic shapes; and beryllium compounds.

You will appreciate that it is misleading to refer to only one producer of beryllium and associated products in Europe, and no doubt you would like to draw the attention of your readers to this fact.

P. Thomas, Manager
Market Development
Consolidated Zinc Corp.
(Sales) Ltd.

A weekly bulletin of engineering positions open is available to AIME members at a subscription rate of $4.50 per quarter or $14 per annum; $4.50 per quarter or $14 per annum for nonmembers, payable in advance. Local offices of the Personnel Service are at 8 W. 40th St., New York 18; 57 Post St., San Francisco; and 29 E. Madison St., Chicago 1.

AIME OFFICERS

R. R. McNaughton	President
Joseph L. Gillson	Past-President
Lloyd E. Elkins	President-Elect
G. I. Brigden	Treasurer
Ernest Kirkendall	Secretary

VICE-PRESIDENTS

John S. Bell	Carleton C. Long
A. B. Cummins	J. S. Smart, Jr.
Wayne E. Glenn	J. W. Woomer

DIRECTORS

James B. Austin	Robert B. Gilmore
Herbert F. Beardmore	James C. Gray
John Chipman	Earl M. Kipp
Richard C. Cole	Richard A. Morse
R. H. Felerabend	W. B. Stephenson
Karl L. Fetters	C. L. Wilson

THE METALLURGICAL SOCIETY OF AIME

J. Stuart Smart, Jr.	President
Carleton C. Long	Past-President
Karl L. Fetters	Vice-President
T. D. Jones	Treasurer
R. W. Shearman	Secretary

BOARD OF DIRECTORS, THE METALLURGICAL SOCIETY

Richard C. Cole	J. H. Jackson
Gerhard Derge	A. E. Lee, Jr.
Harold B. Emerick	J. H. Scaff
R. W. Farley	A. W. Schlechten
W. J. Harris, Jr.	John D. Sullivan
J. H. Hollomon	M. Tenenbaum

SOCIETY PUBLICATIONS COMMITTEE

C. L. McCabe, Chairman

H. L. Bishop	R. E. Lund
K. L. Fetters	W. O. Philbrook
H. H. Kellogg	L. L. Seigle
W. A. Krivsky	R. L. Smith
F. C. Langenberg	F. L. Vogel

Advisory Subcommittee

H. H. Kellogg, Chairman

D. J. Carney	J. J. Harwood
J. F. Elliott	M. L. Hughen
J. R. Freeman, Jr.	E. R. Morgan
B. W. Gonser	T. O. Paine
J. D. Hanawalt	T. A. Read
W. J. Harris, Jr.	A. J. Shaler

editorial

On Training Engineers

Last month, the role of science and technology was discussed in this column. This month the related problem of training engineers for the world of tomorrow is considered, as we continue quoting from Philip Sporn, president of American Electric Power Co.

"In the face of a developing need for more and better-trained engineers . . . educational institutions have been conscientiously striving to meet their responsibilities. Generally they have been increasing their emphasis on mathematics and on science. In many cases they have been allotting some time, or have somewhat increased their already allotted time, to the humanities. But whether realistically evaluated or not, they have, in too many cases, considered they were almost completely bound by historical and rigid precedent as to student time availability. The tradition of graduating a salable product in a particular engineering specialty, and within a limited time, is a strong one."

"In the light of all the above, is it not pertinent to ask how well equipped are the products of such training to solve the engineering problems of the world of tomorrow?

"The answer depends on the kind of engineers we want. If what we are looking for in engineering are people who can solve a particular problem from a specialized, rather narrow, viewpoint, then the kind of curricula we have in many of our engineering schools and the faculties we have to implement these curricula are all good. But if we are looking for people who can take an integrated view of a problem and can place it in its broad social, political, and economic, as well as technical, context . . . then it seems to me that the situation with regard to the adequacy of curricula and of faculty is, in most cases, not so good.

"There are altogether too few places where engineering students are given an opportunity to acquire a firm background in the liberal arts; in history, the history of science and technology; in economics, and political economy, the dynamics of political and social-economic history; and in philosophical and cultural values. Nor are there many places where the attempt is made even to stimulate at least the awareness among engineering students of the importance of integrating these materials into their career activities."

"We simply do not get enough people out of our engineering schools who are able to visualize the larger systems within which the narrow solutions must fit, who can see things in scale and can completely visualize the significance of large industrial complexes at a single location. The conceptualization of a vast aggregation of highly complex machinery and how it relates to the social, economic, and even historical scheme of things is almost utterly beyond them.

"The engineer ultimately is not going to be judged by whether the machinery he has had a hand in designing rotates at a constant speed or a variable speed, or whether the temperature of his metals are at 1100°, 1200°, or 1300°F, or whether his unit stresses are 20, 50, of 100,000 psi. The judgment of society will be based on how the complex he creates functions in society—what it does for society. And by these standards, our current engineering education is, by and large, deficient."

Forging our missile arsenal and spacecraft fleet

Trustworthy metal quality . . . exacting compliance with specifications . . . notable experience with exotic metals and alloys—these are reasons Wyman-Gordon is so often chosen to produce the difficult, the critical, even the predicted "unforgeable" in missile hardware. Specialized facilities, coupled with advanced metallurgical research, offer space-vehicle designers continually expanding frontiers in vital areas of size, complexity, materials and strength-to-weight ratios of forged airframe and propulsion components.

OPERATIONAL and PROTOTYPE HARDWARE PRODUCED

- Re-entry shields
- Domes and closures
- Support beams
- Cones and nozzles
- Pressure vessels
- Motor casings
- Bulkheads and rings
- Turbine components
- Fins and vanes
- Guidance components
- Ground support equipment

WYMAN-GORDON

FORGINGS

of Aluminum Magnesium Steel Titanium . . . and Beryllium Molybdenum Columbium and other uncommon materials

HARVEY, ILLINOIS — WORCESTER, MASSACHUSETTS — DETROIT, MICHIGAN

GRAFTON, MASSACHUSETTS — LOS ANGELES, CALIFORNIA — PALO ALTO, CALIFORNIA — FORT WORTH, TEXAS

PROCESS VARIABLES IN PLASMA-JET SPRAYING

The introduction of commercial plasma-jet equipment has rapidly advanced the technology of spray coating. This paper briefly reviews some of the experimental data collected during several past investigations with the hope of stimulating further experimental and theoretical work in this field.

by D. R. Mash, N. E. Weare, and D. L. Walker

The technology of spray coating is undergoing rapid advancement as a result of the commercial introduction of plasma-jet equipment. Advantages of this new tool over previously available spray-coating equipment, such as oxy-hydrogen and oxy-acetylene units, are associated with higher operating temperatures and use of inert gases which provide the means of melting and spraying almost any material without contamination. Successful development of plasma-jet spraying processes will provide a valuable method for production of coatings for thermal protection systems, corrosion- and wear-resistant coatings, and advanced types of nuclear fuel elements. Even at this relatively early stage, however, it is generally recognized that problems involved in spraying a variety of materials are more complex than first indicated.

Over the past several years, the Materials Dept. of Advanced Technology Laboratories has been conducting a variety of investigations of plasma-jet spraying for nuclear, missile, and industrial applications. To the maximum extent in every case, the approach employed has been to emphasize systematic development of data relating the numerous process variables associated with plasma-jet spraying. Studies of this kind, coupled with extensive analytical work, are yielding valuable information on a wide range of coating materials, sprayed on various substrates. Results of such studies are believed to be of great importance to the industry if progress is to be made in realizing the great potential of this novel fabrication technique. Therefore, the chief purpose of this paper is to review briefly some of the experimental data collected during several past investigations with the hope of stimulating additional experimental and theoretical research efforts in this field. As a result of such work, plasma-jet spraying technology can be expected to grow steadily on a sound scientific basis, rather than resting on pure empiricism.

The data in this paper includes work performed by the Materials Dept. of ATL under programs supported by American-Standard, by the Re-Entry Systems Dept. of Lockheed Aircraft Corp., Missiles and Space div., and by the joint US-EURATOM Research Board.

D. R. MASH, N. E. WEARE, and D. L. WALKER are with Advanced Technology Laboratories div. of American-Standard, Mountain View, Calif. This paper was presented at the AIME's sponsored sessions of the 1961 Western Metals Congress.

Equipment

Equipment required to carry out this work on either an experimental or production basis includes: plasma-jet spray guns, power supplies, control consoles, water circulation systems, powder feed systems, sandblasters, and assorted powder sizing equipment. In addition, many materials must be sprayed in inert-atmosphere chambers.

The equipment utilized in these investigations included Plasmadyne SG-1 plasma-spray systems having a rated power output of 25 kw when using

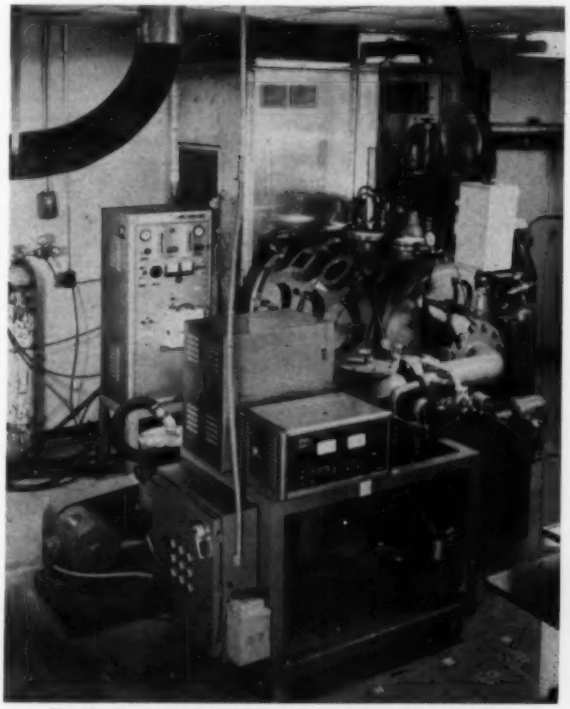


Fig. 1—Large inert-atmosphere plasma spray chamber.

argon as the arc gas. The essential features and operating principles associated with this type of equipment have been discussed in numerous technical and popular articles, as well as manufacturers, publications. For spray applications, powder is injected into the plasma by means of a hole drilled through the front electrode, and canted back toward the arc chamber about 5°.

For powder feeding, ATL experience has indicated clearly that a screw feed hopper system, such as the Continental Coatings Corp. system, provides the most acceptable and consistent results.

Substrate cooling was accomplished by clamping the substrate on a water-cooled chill block. When required, cooling of the coating was accomplished by directing jets of helium or argon gas at the coating surface.

Many materials must be sprayed in an inert atmosphere to prevent oxidation or decarburization. To accomplish this, the plasma jets were mounted in vacuum-purged, inert-atmosphere chambers as illustrated in Fig. 1. All materials discussed in this paper, with the exception of ZrO_2, were sprayed in inert atmospheres. Automatic traversing devices were designed and installed to move the substrate beneath the plasma torch. This completely eliminated the *human element* associated with manual manipulation of the plasma jet.

In order to conduct a plasma-spray program, considerable support equipment is required. To prepare the powders for spraying, balances, blenders, sieves, sieve shakers, and drying ovens were employed. Wet classifying equipment was used to deslime powders or cut sub-sieve powders into size fractions. Substrate surface preparation was by sandblasting in either a suction- or pressure-type blasting system.

Materials and experimental procedures

Several powders were sprayed on a number of substrates during the course of the research programs discussed herein. Pertinent information relative to powders and substrates included in this discussion is given in Table I.

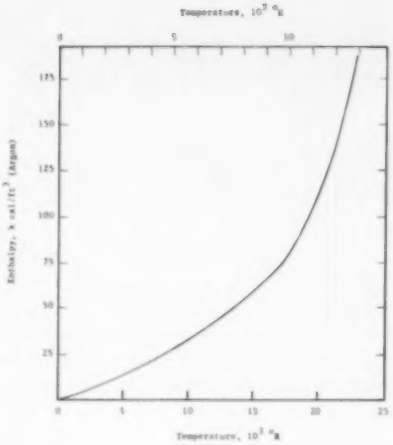


Fig. 2—Relationship between enthalpy and temperature of argon plasma at 1 atm.

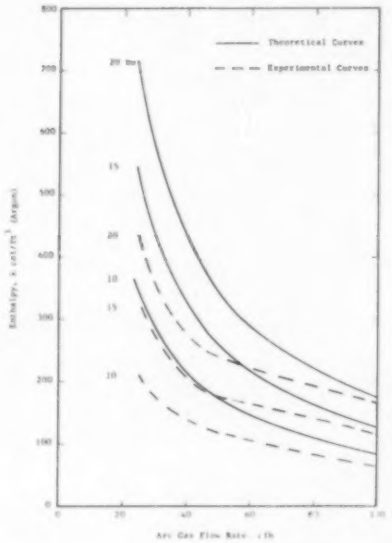


Fig. 3—Enthalpy of argon plasma as a function of arc gas flow for various power input levels.

Table I. Summary of Data on Selected Materials and the Substrates Upon Which Coatings Were Made

Powder	Types	Composition, wt pct	Size Ranges Sprayed, μ	Supplier	Substrates
ZrO_2	Fused, Sintered, Chemically Treated	5 CaO, bal. ZrO_2	74-104 61-74 43-61 <43	Zirconium Corp. of America	304 Stainless Steel Aluminum Zircaloy-2 Mild Steel
UO_2	Fused	88.2 U, bal. O	43-74 43-53 <38*	Spencer Chemical Corporation	304 Stainless Steel Aluminum Zircaloy-2 Mild Steel
TiC	—	19.53 C, 0.04 Free C, 0.45 Impurities, bal. Ti	74-147 43-74 12-43 5-30	Kennametal, Inc.	Beryllium
ZrC	High-Purity	84-87 Zr, 10-12 C, 0.5-0.75 N	43-74 12-43	Norton Electro-Chemical Division	Beryllium
TaC	—	6.25 C, 0.01 Free C, 0.32 Impurities, bal. Ta	43-74 12-43	Kennametal, Inc.	Beryllium
TiN	Technical Grade	75-77 Ti, 18-19 N, 1-2 C	43-74 12-43	Norton Electro-Chemical Division	Beryllium
Steel	4340	0.42 C, 0.99 Cr, 1.83 Ni, 0.27 Mo, 0.66 Mn	43-74	Vanadium Alloy Steel Co.	Aluminum

* De-slimed

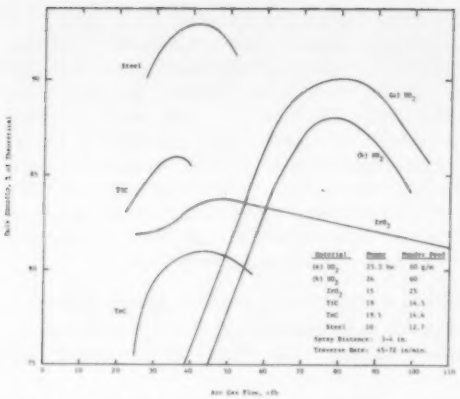


Fig. 4—Left, effect of arc gas flow on bulk density of coatings.

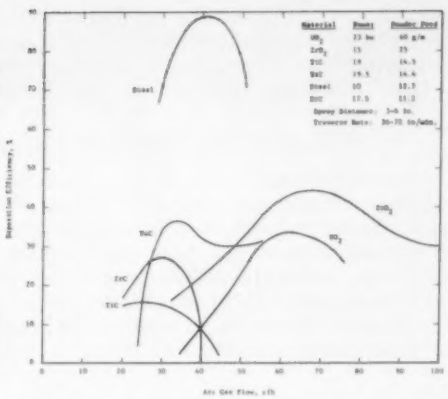


Fig. 5—Right, effect of arc gas flow on deposition efficiency.

Several types and sizes of powders were sprayed to determine the effect of spraying variables on coating density and deposition efficiency. However, the effect of particle size, distribution, and powder history is beyond the scope of this paper, and all results are limited in general to those powder conditions shown in Table I.

Powder to be sprayed was sized, deslimed if necessary, and loaded into the Continental feed hopper. Substrates were prepared by sandblasting, followed by a cleaning operation to remove embedded blasting medium. Silicon carbide was normally used as the blasting medium.

Prepared powders were placed in the feed hopper and substrates mounted on the chill block for spraying. In order to study the effects of the variables, coatings were sprayed at different values of the variable under study while the remaining conditions were held constant at predetermined values.

Sprayed coatings were evaluated primarily for density, deposition efficiency, and deposition rate to determine the effect of spraying parameters. Density was measured by immersion in water, using a thin plastic film to seal the coating pores. Volumes displaced by the substrate and plastic film were calculated from known weights and predetermined densities. Providing that a minimum coating volume of at least 2 cu cm was deposited on a 5x5 cm (2x2 in.) substrate, the error in calculating the percent theoretical density was less than 1 pct.

Deposition efficiency is defined as the weight percent of powder fed to the plasma torch which formed the coating. Absolute values were determined from the coating weight, the known powder feed rate, and spraying time.

Plasma-Spray variables

Variables associated with plasma-jet spraying can be categorized, as shown in Table II. In addition, pertinent coating properties are listed. Major at-

Table II. Classification of Plasma-Spray Variables and Pertinent Coating Properties

Process Variables Listed by Category

Plasma
1. Power Input
2. Type of Arc Gas*
3. Flow of Arc Gas
4. Plasma-Torch Geometry*

Powder
1. Composition
2. Physical Properties
3. Method of Manufacture*
4. Powder Size
5. Particle Size Distribution*

Powder Feed
1. Type of Powder Feed System*
2. Rate of Powder Addition to Carrier Gas
3. Type of Carrier Gas*
4. Flow of Carrier Gas
5. Angle of Powder Entry into Plasma*
6. Location of Powder Entry Port*

Spraying Procedure
1. Torch-to-Work Distance
2. Traverse Rate
3. Angle of Torch with Work*
4. Cover Gas*
5. Spraying Atmosphere*

Substrate
1. Composition*
2. Surface-Preparation Method*
3. Surface Roughness*
4. Temperature*

Coating Properties or Characteristics Evaluated

A. Density
B. Microstructure*
C. Adherence*
D. Deposition Efficiency and Rate
E. X-ray Diffraction Analysis of Crystal Structure*
F. Chemical Composition*

* These variables, properties, or characteristics are being studied in current programs but for the sake of simplicity, are not discussed within this paper.

Table III. Physical Properties of Typical Materials for Plasma-Spray Applications

Material	Molecular Wt	Melting Point, °C	Density, g/cc	Sp. Ht., cal/g/°C	Thermal Cond., cal/sec-cm-°C	Coeff. Exp. /°C	Heat of Fusion, cal/g	Available Powder Quality*
ZrO_2	123	2690	6.27	0.16	0.005	8.7	—	A
UO_2	270	2880	10.96	0.075	0.02	10	68	B
TiC	60	3250	4.93	0.201	0.04	7.5	—	A
TaC	193	3900	14.65	0.038	0.053	8.2	—	A
ZrC	103	3530	6.73	0.15	0.05	6.7	—	C
TiN	62	2950	5.43	0.19	0.07	—	322	C
B_4C	56	2450	2.52	0.443	0.065	4.5	—	C
Steel-4340	56	1500	7.84	0.13	0.08	12	65	A
Steel-304	56	1400	7.92	0.15	0.06	19.2	—	A
Tungsten	184	3380	19.3	0.033	0.4	4.5	61	A

* Legend refers to performance of commercially available powder in plasma-spraying experiments: A = Good, B = Acceptable, and C = Poor.

tention in this paper is given those variables associated with equipment and procedures. Pertinent properties include deposition efficiency and, to some extent, deposition rate and coating density.

Variables Associated with Powder

Powder variables were not extensively examined, although they were recognized to be of extremely great importance. Work discussed in this paper has been conducted chiefly using commercially available materials. Some effort is in progress at ATL on the determination of optimum powder size, distribution, and history. However, a much more comprehensive program along this line is needed.

Table III lists physical properties of a variety of materials currently being plasma sprayed. This data can be utilized to estimate the maximum particle size which can be melted. Calculated particle sizes are given in Table IV together with several other parameters which are useful for comparing materials. Experimental work does not completely confirm predictions based on such comparisons, indicating the great importance of other factors, such as powder quality. The Appendix further treats analytical aspects of plasma spraying.

Variables Associated with the Plasma Jet

Power input, arc-gas type and flow, and geometry of the plasma jet affect the operating characteristics

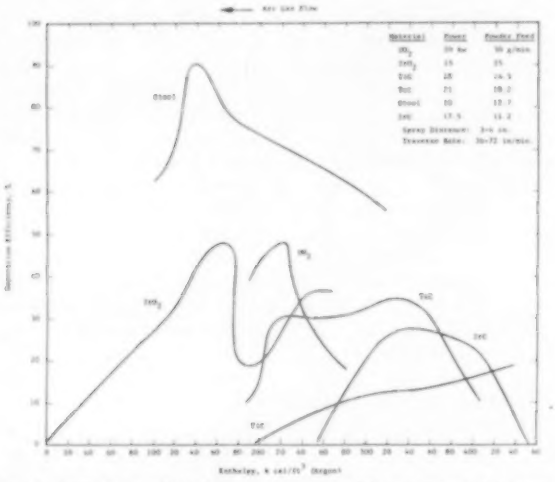


Fig. 6—Deposition efficiency as a function of heat content of argon plasma (arc gas flow variable).

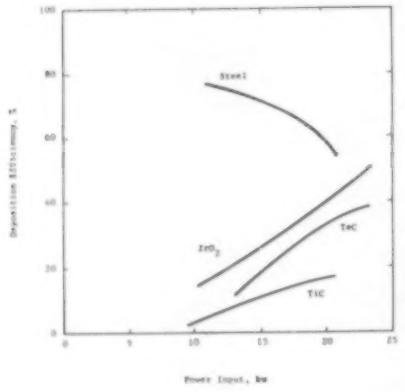


Fig. 7—Effect of power input on deposition efficiency.

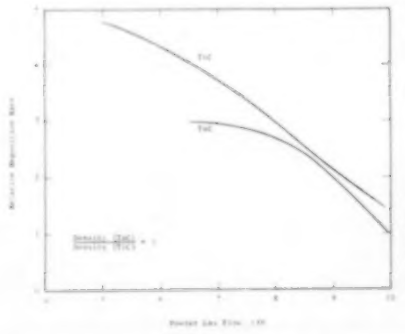


Fig. 8—Effect of powder gas flow on relative deposition rate of TiC and TaC.

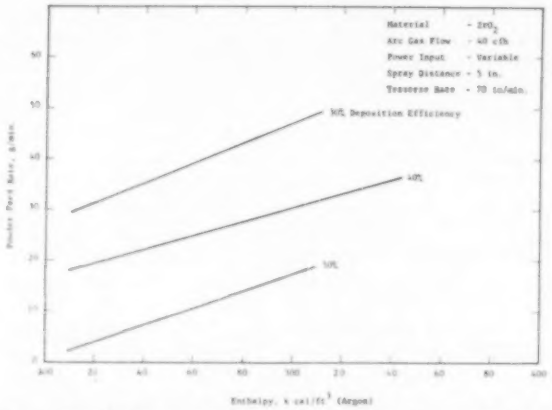


Fig. 9—Powder feed rate as a function of argon plasma enthalpy to achieve various deposition efficiency levels.

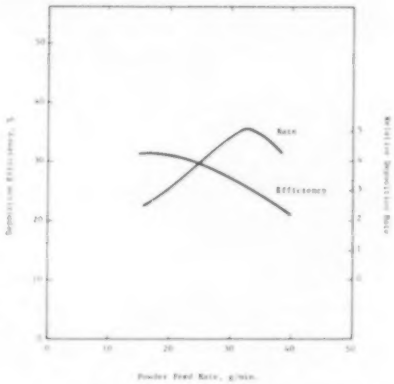


Fig. 10—Effect of powder feed rate on efficiency and deposition rate of TaC.

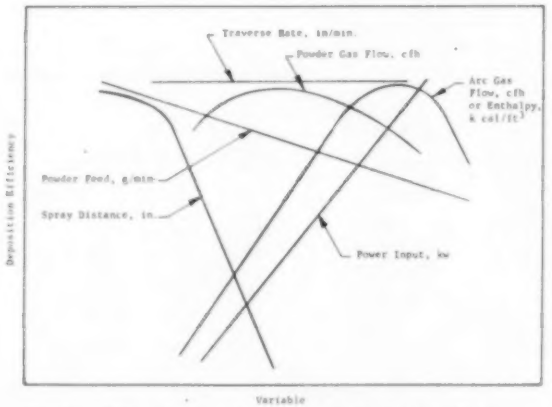


Fig. 11—Effect of selected variables on deposition efficiency.

of the plasma. Argon was used throughout the current investigations due to its inertness. Only one design of plasma jet was used, having a fixed geometry. Thus, the only variables studied were power input and arc-gas flow rate. Before discussing the effects of these variables on spraying, it will be of interest to discuss the effects on the plasma characteristics.

The temperature in a plasma jet is dependent upon the heat or energy content of the gas. Fig. 2 illustrates this relationship. It can be seen that extremely high temperatures are present in a plasma jet. Temperature is not as important as the heat content of the gas; however, it does provide the driving force for the transfer of heat to the particles. Even at low enthalpies, gas temperatures are above the melting points of most materials being sprayed.

One of the most important considerations in plasma-jet spraying is the enthalpy or heat content of the plasma. Theoretical values can be calculated from the power input and gas flow through the torch. Actual enthalpies differ greatly from the theoretical values. Experimental enthalpies were calculated by determination of the power lost to the cooling water by calorimetric techniques. Fig. 3 illustrates the theoretical and experimental heat contents at various arc-gas flow rates and at three levels of power. Low arc-gas flow rates provide the highest heat content. The rate at which enthalpy decreases diminishes as gas flow increases. Experimental values were found to be about 50 to 80 pct of the theoretical values at low and high arc-gas flow rates, respectively.

Arc-gas flow rate influenced coating density and deposition efficiency, as shown in Figs. 4 and 5. It is obvious that both of these characteristics are affected in the same manner by this variable. Such behavior is typical of what was observed during these studies. Generally, changes in values of process variables resulted in greater changes in deposition efficiency than in coating density. Therefore, deposition efficiency is used throughout this paper to illustrate the effects of spraying variables. Figs. 4 and 5 show that optimum values of arc-gas flow tend to group the materials according to type: carbides and oxides.

Fig. 6 illustrates deposition efficiency as a function of enthalpy, which has been varied by means of arc-gas flow rate. An optimum combination of enthalpy, dwell time, and particle velocity appears to exist for maximum efficiency. Comparison of this figure with Fig. 5 shows that enthalpy is the more appropriate independent variable for use in this type of study. Decreasing deposition efficiency with increased enthalpy beyond the optimum shown is explained primarily by poor powder feed conditions at low arc-gas flows. The efficiency of steel probably decreases because of vaporization at high values of enthalpy.

As shown in Fig. 7, power input within the ranges available for study had a significant effect on deposition efficiency which is associated with enhanced particle melting. However, optimum values of arc-gas heat content will be reached beyond which further increase in power will not effect significant improvement. In fact, once complete particle melting has been achieved, higher gas temperatures may prove harmful, as in the case of steel. At some values of enthalpy, vaporization may take place, thus lowering deposition efficiency. This trend was noted only for steel which has a boiling point at about the same temperature as the melting points of the other materials considered.

Variables Associated with Powder Feed

A balance must be maintained between arc-gas and powder-gas velocities to position the powder particles in the plasma for proper melting. Therefore, the flow of powder gas is a very important consideration. The effect of powder gas flow is illustrated in Fig. 8, where deposition rate (proportional

Table IV. Comparison of Typical Materials for Plasma-Spray Applications

Material	Diffusivity, sq cm/sec	$C_p(T_{mp}-T_1)$ cal/g	d^a_{max}, microns	Calculated Relative Ease[b] of Plasma Spraying
ZrO_2	0.005	430	26	5
UO_2	0.025	214	58	4
TiC	0.04	645	72	3
TaC	0.09	115	110	1
ZrC	0.05	525	82	3
TiN	0.07	556	96	2
B_4C	0.06	109	90	2
Steel-4340	0.08	195	104	1
Steel-304	0.05	226	82	3
Tungsten	0.63	111	280	1

[a] Calculated maximum particle diameter for reaching a center temperature of 0.9 melting point in 100 microseconds residence time in plasma jet. (See Appendix).

[b] Based on d_{max}. Indicates degree of control necessary for satisfactory coatings. Group 1 materials can be sprayed using a wide range of conditions, while Group 5 requires a relatively narrow range.

Table V. Summary of the Conditions Determined for the Highest Deposition Efficiencies

	Material					
	ZrO_2	UO_2	TiC	ZrC	TaC	Steel
Power Input, kw	>20*	>20*	>19.5*	16	>21*	10
Arc-Gas Flow, cfh	60	60	25	30	30	40
Powder Feed Rate, g/min	<10	30	<12	12	<15	<9
Powder Gas Flow, cfh	5	6	5	6	6	7
Spray Distance, in.	4	4	3.5	2	3	3-4
Traverse Rate, in./min.	70	80	72	40	72	45
Cover-Gas Type and Flow, cfh	None	None	He 250	He 250	He >160	He 160
Powder Size, μ	43-74	43-74	12-43	12-43	12-43	43-74

* Limit of equipment.

to efficiency) is plotted as a function of powder-gas flow for materials of different densities.

Fig. 9 illustrates the relationship between enthalpy and powder feed rate to achieve a specified deposition efficiency. It is readily seen that as enthalpy is increased, a greater amount of powder can be injected into the plasma and melted. Deposition rate increases as powder feed rate is increased, as shown in Fig. 10. A maximum rate was noted for several materials which represents a point where the decreasing efficiency is great enough to affect the rate. Thus it is apparent, when economics is considered, that a choice can be made between optimum deposition efficiency and higher scrap or reprocessing costs.

Summary

Results of current plasma-jet spraying investigations have shown the effects of numerous process variables on deposition efficiency and coating density. Fig. 11 illustrates schematically the manner in which specific variables affect deposition efficiency. Variables which can greatly influence efficiency include: power input, arc-gas flow, and spray distance. Moderate effects result from varying the powder feed rate and powder gas flow rates within reasonable limits. Changes in traverse rate have little or no effect on deposition efficiency and density.

Using the SG-1 spraying system, conditions were established which produced the best deposition efficiencies within the limitations of the equipment. Table V lists these conditions for the spraying of selected materials.

In addition to obvious improvements in equipment design which will develop with time, problems arising from powder technology must be solved. In the case of many powders, available materials are unsatisfactory for plasma spraying.

Research in the field of plasma spraying is now producting data concerning fundamentals of the process. These programs also are defining areas for future research efforts. Much more experimental work is needed along lines reported here on a variety of coating materials. This work should be supported by a substantial effort involving theoretical analysis of heat transfer and hydrodynamic aspects of the plasma-spray process. In addition, the following areas of investigation are believed to be of great importance, and effort along these lines is strongly recommended:

1) Investigation of basic plasma-spraying parameters with the objective of developing improved equipment;
2) Determination of basic physical properties of powders which influence applicability to the plasma-spray process; and
3) Investigation of optimum powder characteristics for plasma spraying with the objective of developing useful materials specifications.

Appendix

Heat transfer and hydrodynamic problems associated with plasma-jet spraying are extremely complex and clearly merit attention if progress is to be made toward a fundamental understanding of this technique. Some effort in this direction has been initiated at several laboratories, including ATL; however, the immediate need for estimating performance and applicability of materials to plasma-jet spraying must be satisfied by using analyses based on rough approximations of the physical situation. A helpful approach, currently is to compare materials on the basis of physical properties combined into rather well known heat transfer parameters such as the Fourier number (Fo). This analysis leads to the calculation of a particle size which can be used as an indication of ease of plasma spraying. Comparing these values for various materials permits tentative process conditions to be established for initiating an experimental program. A clearer understanding of seemingly contradictory experimental results can be achieved by using the analytical approach.

A treatment of convective heat transfer is beyond the scope of this discussion. However, a straightforward method of making qualitative estimates of materials performance can be described which leads to results such as those presented in Table IV. Maximum particle diameter for essentially complete melting, d_{max}, provides a useful figure for comparison of materials of widely different densities and thermal properties.

Calculation of d_{max} is based on the normal equation for transient heat conduction in solid spheres assuming that the surface of the particles is brought instantaneously to the melting point. This equation is

$$\frac{T_m - T_r}{T_m - T_i} = \phi_1 \text{ (Bi, Fo)} = \phi_1 \left[\frac{hr_o}{k}, \frac{\alpha \theta}{r_o^2} \right] \quad [1]$$

where T_m = Melting point of the material
T_r = Temperature at points along the radius of a spherical particle: $r = o$ at center of sphere and $r = r_o$ at surface of sphere
T_i = Initial temperature of particle, approximately 20°C
α = Diffusivity, sq cm per sec $= \frac{k}{\rho C_p}$
θ = Time, seconds
Bi = Biot Modulus
Fo = Fourier Number

At the center of the particle, $r = o$, Equation [1] becomes approximately

$$1 - \frac{T_o}{T_m} = \phi_1 \left[\frac{hr_o}{k}, \frac{\alpha \theta}{r_o^2} \right] \quad [2]$$

Values of d_{max} shown in Table IV were calculated by assuming a constant dwell time (θ) of 100 microseconds, a center temperature (T_o) of 0.9 T_m, and a value of 1/Bi of about 0.1. Fo is found to be about 0.3 from Heisler or Gurney-Lurie charts which are available in standard works on heat transfer. The value of d_{max} for the above conditions was calculated for each material from the relation

$$d_{max} = 2\, r_o = 2 \left[\frac{\alpha \theta}{0.3} \right]^{1/2} \quad [3]$$

Such comparisons are very approximate and, as shown in this paper, must be supplemented by considerable knowledge of actual behavior under a range of experimental conditions. It is hoped, however, that future work in both theoretical and experimental areas will produce considerably refined treatments of the plasma-spray problem so that much of the current empirical knowledge may be restated in scientific terms to produce a sound technology.

PLASMA SPRAYING TECHNIQUES FOR TOXIC AND OXIDIZABLE MATERIALS

Plasma spraying has made it possible to deposit materials which were heretofore considered as unsprayable. Two categories of materials are discussed —materials which have a toxicity problem associated with their handling, and those which undergo rapid oxidation and composition changes when sprayed in air.

by A. R. Stetson and C. A. Hauck

Until very recently, the field of flame and plasma spraying has been largely limited to the deposition of simple, low-cost, oxides and metals melting under 5000°F. Flame spraying, because of the low flame temperature and corrosive action of exhaust products, is limited to this area. Plasma spraying, however, has provided new capabilities, and many materials can now be sprayed which heretofore were classified as unsprayable.

In this paper, two categories of materials are discussed: materials which have a toxicity problem associated with their handling, and materials which cannot be sprayed in air because of rapid oxidation and composition change. In the first category are beryllium and beryllium oxide. In the second category are titanium carbide, tantalum carbide, zirconium carbide, and titanium nitride.

Beryllium-containing materials

Particulate beryllium and beryllium oxide, which must be handled in plasma spraying, are extremely toxic. Acute pneumonitis can result from exposure. This disease is insidious and varies in severity with individual tolerances. Because of this danger, the occupational limits of beryllium in air (set by the US Atomic Energy Commission) are extremely low, i.e., only 2 micrograms per cu m in an 8-hr day, or 25 micrograms per cu m for 30 min.

To reduce the beryllium concentration to the AEC permissible levels requires enclosing the plasma torch in a chamber provided with a ducting and filtration system to remove the beryllium-containing dust. A layout of the system used at Solar Aircraft Co. is shown in Fig. 1. Briefly, the system consists of:

1) A spray chamber which is a modified Kewaunee dry box,

2) A Torit No. 75 combination 350-cfm blower and bag filter,

3) A Mine Safety Appliance 1000 cfm, Ultra Air Space Filter (No. CU82144), and

4) 4-in. diam ducting

A. R. STETSON and C. A. HAUCK are with Solar Aircraft Co., San Diego, Calif., a subsidiary of International Harvester Co. This paper was presented at the AIME sponsored sessions of the 1961 Western Metals Congress.

The filtration system is capable of removing 99.97 pct of the particulate material down to 0.3 micron in diam. Ducting size was selected to provide a minimum air velocity of 2500 ft per min.

The frontal openings on the spray chamber are restricted in size to provide a minimum air velocity of 2000 ft per min. The large glass view area on the spray chamber also is restricted to 36 sq in. to prevent cracking of the glass during torch operation. Location of the plasma torch and specimen holder are shown in Fig. 2.

To evaluate the effectiveness of the toxicity controls, air sampling with a Staplex Hi-Volume Air Sampler was performed during both spraying and powder transfer. Location of sampling was primarily at the operator level near the dry box, but the absolute filter exhaust and laboratory work area outside the spray area were also monitored. Results of these tests are shown in Table I. The results show that maintenance of the recommended operating limits within the laboratory, particularly during material transfer operations, was difficult. Because of this difficulty, an approved face mask was required during transfer and during spraying of beryllium oxide, but not during spraying of beryllium.

Equipment

The spray gun used in this work was designed and built by laboratory personnel. In operation, this gun was very adaptable to experimental coating development because of the ease of modification and availability and low cost of replacement parts. The power supply and control console, rated at 40 kw, was purchased from Giannini Plasmadyne. A Continental Coating Corp. Flame Ceramic Powder

Table I. Beryllium Air Sampling Tests

Operation or Location	Material	Beryllium Concentration, μ gm/cu m
Material transfer	Be	21.0
Material transfer	Be	13.4
Material transfer	Be	1.6
Spraying	Be	2.8
Spraying	Be	0.9
Spraying	BeO	3.3
Spraying	BeO	4.3
Filter room	—	0.02
Exhaust of absolute filter	—	0.53

Table II. Operating Parameters and Properties of Plasma-Sprayed Beryllium

Material	
Berylco HPA Grade −200 mesh powder, −325 fraction used.	
Operating Parameters	
Power	21 kw
Plasma Gas (Argon)	
5/16-in. diam nozzle	120 cu ft/hr
1/4-in. diam nozzle	90 cu ft/hr
Powder Carrier Gas (Argon)	16 cu ft/hr
Surface Coolant	CO_2

Properties

Spraying Distance, in.	Bond Strength, psi	Density, pct
1	3005*	89.6
2	2420	—
3	1791	—

* Adhesive failure

Table III. Operating Parameters and Properties of Plasma Sprayed Beryllium Oxide

Material	
Berylco Grade 3—BeO high-fired and milled. Size: −230, +325 mesh	
Operating Parameters	
Power	30 kw
Plasma Gas (Argon)	70 cu ft/hr
Powder Carrier Gas	16 cu ft/hr
Plasma Torch Nozzle	¼ in. diam
Spray Distance	1½ in.
Coolant	CO_2
Adherence	310 psi*

* Cohesive failure.

Feeder was used to feed the powders to the spray gun. This positive-feed, auger-type device provides reliable powder feeding even for extremely fine powders.

Plasma Spraying

The plasma spraying of Be and BeO was performed on 1-in. diam steel or beryllium specimens. One end of the specimen was drilled and tapped for ease of holding and adherence testing.

The beryllium sprayed was Berylco HPA grade, −200 mesh powder. Sieve analysis of this powder showed 49 pct +325 mesh. In the initial spraying of this powder, considerable trouble was encountered in premature melting and agglomeration of the powder in the torch nozzle. Erratic torch operation and extremely rough coating deposits were produced. By elimination of the +325 size fraction and increasing the plasma gas flow and powder carrier gas flow to high levels, excellent deposits were obtained.

Table II shows operating conditions and adherence and density test results on sprayed beryllium. Adherence was determined by bonding two coated test specimens together with Eastman 910 adhesive and pulling them apart on a tensile tester. Density

Table IV. Physical and Thermal Properties of Materials

Material	Melting Point, °F	Specific Heat, Btu/lb/°F	Specific Gravity
TiC	5900	0.20	4.9
TaC	7020	0.06	14.5
ZrC	5750	0.12	6.4
TiN	5330	0.19	5.2
Be	2345	0.67	1.85
BeO	4660	0.50	3.03

Table V. Plasma Spray Powders and Plasma Gun Operating Parameters

Powder	Source	Grade	Specified Size	Size Fraction	Plasma* Gas Flow, cu ft/hr	Carrier* Gas Flow, cu ft/hr	Nozzle Size, in.	Power Level, kw	Spray Distance, in.
TiC	TAM	HFC	−325				Sprayable		
TiC	Norton	Tech	−325				Sprayable		
TiC	Kennametal	MP-50	−200				Not Sprayable		
			+325						
TiC	Kennametal	MP-50	−325				Sprayable		
TiC	Kennametal	MP-50	5 to 30		90-60	16	1/4-5/16	25-27	2-3
TaC	Shieldalloy	1	−325				Sprayable		
TaC	Kennametal	MP-60	−100				Not Sprayable		
TaC	Kennametal	MP-60	−400		90-60	16	1/4-5/16	25-27	2-3
ZrC	Norton	Exp	−100		60	16	5/16	27	3
TiN	TRG		−400		50	13	5/16	27	3

* Argon Gas.

Table VI. Chemical Analysis of Titanium and Tantalum Carbides

Material	Stoichiometric, pct	As Received		Sprayed in Air		Sprayed in Argon (1 pct O_2)		Sprayed in Argon (0.1 pct O_2)	
		C, pct	O_2, pct	C, pct	O_2, pct	C, pct	O_2, pct	C, pct	O_2, pct
TiC TAM high Free C Grade	20.05	21.5	0.9	11.0	5.04	—	—		
TiC Kennametal MP-50 −325 mesh	20.05	20.0	0.25	14.1	7.0				
TiC Kennametal MP-50 5 to 30 microns	20.05	20.7	0.25			17.8	2.5	20.5	0.27
TaC Shieldalloy Grade 1 −325 mesh	6.23	6.4	0.24	1.4	2.4				
TaC Kennametal MP-60 −400 mesh	6.23	6.4	0.07	—	—	—	—	5.6	0.24

was determined by the water immersion method on coatings removed from the substrate.

The inverse relationship of adherence to spray distance is typical for sprayed metals. Thermal insulators and brittle material do not necessarily exhibit this inverse relationship, since thermal stresses within the coatings tend to limit the maximum permissible surface temperature.

Plasma spraying of beryllium oxide is greatly restricted by the type of powders available commercially. Currently, only agglomerate–type powders are available. These consist of approximately 1-micron powder agglomerated to larger sizes, such as 20 to 60 microns. Beryllco Grade 3 powder, which is $-230 + 325$ mesh is a typical example. These powders not only tend to clog the powder feed mechanism, but tend to break apart and volatilize rather than melt in the plasma.

Poor quality, relatively soft beryllium oxide coatings were obtained. These coatings had high porosity and were limited in thickness to 0.030 in. by the high surface temperature required for deposition. Table III shows the operating condition used for deposition.

It was found that by maintaining the substrate at a constant elevated temperature, e.g., 800°F, and by minimizing the torch dwell time and cooling with carbon dioxide, beryllium oxide coatings 0.090 in. in thickness could be obtained. These thicker coatings, however, would spall at the coating substrate interface on cooling to room temperature. Application of a variety of bond coats and graded beryllium-beryllia composition did not appreciably extend the coating thickness limit.

Before better beryllium oxide coatings can be obtained, dense powders of beryllium oxide, preferably fused, must be made available.

Carbides and Nitrides

Plasma spraying the carbides and nitrides presents no toxicity problems, but the poor oxidation resistance of these materials makes spraying in protective atmosphere mandatory. For this controlled atmosphere spraying, the chamber shown in Fig. 3 was constructed. It consists of a water-cooled, gas-tight shell with the plasma spray gun mounted in a fixed position on the outside of the chamber. The sample holder is a long, water-cooled tube extending into the chamber through a stainless steel bellows that permits the sample to be manually sprayed at a controlled distance. The

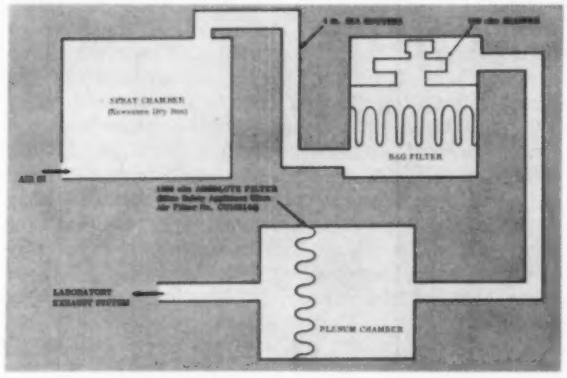


Fig. 1—Air filtration system for control of beryllium dust.

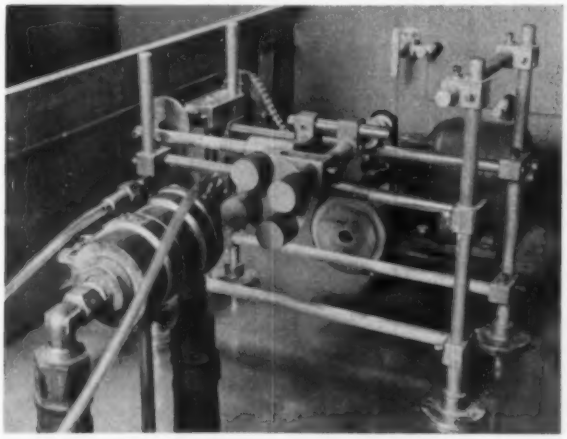


Fig. 2—Spray fixtures and plasma torch.

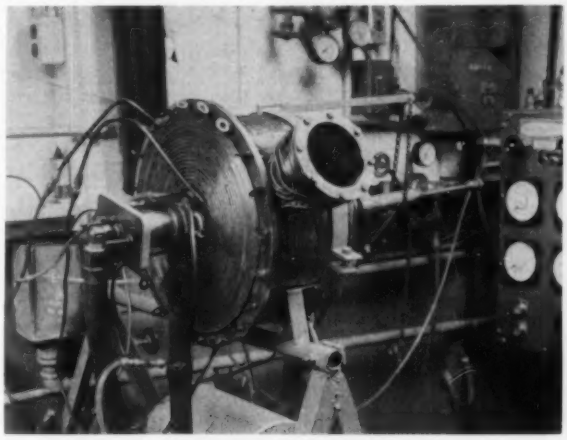


Fig. 3—Controlled atmosphere spray chamber.

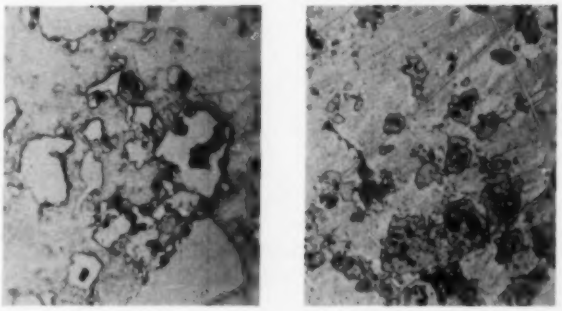


Fig. 4—Left, titanium nitride, —400 mesh. Right, zirconium carbide, —325 mesh. Both at 500X, reduced 50 pct for reproduction.

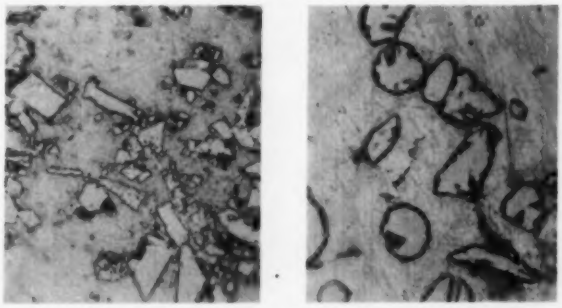


Fig. 5—Left titanium carbide, 5 to 30 microns. Right, tantalum carbide, —400 mesh. Both at 500X, reduced 50 pct for reproduction.

specimen holder accommodates 1- and 2-in. diam, ¼ in. thick specimens. Back side water-cooling and front side argon-cooling are built into the chamber.

The carbides and nitrides were selected for spray evaluations because of availability and current interest in these materials as possible thermal insulators in re-entry structures and rocket nozzles. The fact that these materials are among the highest-melting substances known also added interest. A few of the physical and thermal properties of the compounds are given in Table IV.

Material from a number of sources was obtained and sprayed. Sources and spraying parameters are given in Table V. From this preliminary spray work and the chemical composition of the materials, it was determined that Kennametal's 5 to 30 micron TiC powder, and Kennametal's — 400 mesh TaC powder had the most desirable spraying properties. With the exception of the coarse TiC and TaC, all of the material could be sprayed. The available zirconium carbide and nitride powders had very poor spray properties.

Atmosphere composition in the spray chamber had a pronounced effect on the composition of the sprayed deposit, as shown in Table VI. As little as 1 pct O_2 reduced the carbon content in titanium carbide from 20.7 to 17.8 pct. Spraying in air reduced the carbon content in TaC from 6.2 to 1.4 pct, and in TiC from 20 to 14 pct. To maintain stoichiometric carbon ratios in TiC required an oxygen content below 0.1 pct. With TaC, even this low oxygen level did not prevent carbon loss below the stoichiometric value. Volatilization may account for part of the carbon loss in the very high melting TaC, i.e., 7020°F.

Properties of the plasma-sprayed titanium carbide (Kennametal MP-50, 5 to 30 micron grade) and tantalum carbide (Kennametal MP-60 — 400 grade) are shown in Table VII. Other materials are also included in this table for comparison. Results show density is quite constant between 89 and 91 pct, with the exception of the result for zirconium carbide, which was only 80 pct. Spray distance and power input within the range studied had little effect on the property. Adherence was also relatively constant for the carbides, varying only between 900 and 1000 psi. Adherence or coherence, however, was only about one third that achieved with beryllium, but more than three times that for beryllium oxide.

Impact resistance, tested by the falling weight method using a 1-in. diam ball impactor, was very high for the carbides. On the ¼-in. thick 1-in. diam beryllium substrates used in testing, failure of the substrate occurred prior to failure of the 0.030 to 0.050 in. thick coatings. A tantalum carbide coated, impact test specimen after testing showed considerable substrate deformation with no evidence of cracks developing within the coating.

Table VII. Properties of Plasma-Sprayed Material

Coating	Substrate	Power Level, kw-hr/cu ft	Spray Distance, in.	Density, pct Theoretical	Adherence, psi	Impact, ft-lb
Be	Steel	0.2	1	89.6	3005[c]	—
Be	Steel	0.2	2	—	2420[d]	—
Be	Steel	0.2	3	—	1790[d]	—
BeO	Be	0.35	1.5	—	310[b]	—
TiC	Be	0.24	2	89	960[b]	>12[a]
TiC	Be	0.36	3	91	910[b]	>12[a]
TaC	Be	0.24	2	91	920[b]	>12[a]
TaC	Be	0.36	3	91	1020[b]	>12[a]
ZrC	Be	0.36	3	80	—	—
TiN	Be	0.43	3	—	—	—

[a] Substrate failure.
[b] Cohesive failure.
[c] Adhesive failure.
[d] Bond failure.

Titanium nitride and zirconium carbide were among the oxidizable materials included in this plasma spraying study. These materials sprayed very poorly due to several factors:

1) The titanium nitride partially dissociated in spraying yielding a very fine deposit in the spray chamber. X-ray diffraction showed evidence of the presence of alpha titanium in the sprayed material. Titanium nitride had better appearance when sprayed in air but was badly oxidized.

2) The size-range distribution in these powders was very large, i.e., 1 to 40 microns. Volatilization of the fine particles appears to lower the plasma temperature. Deposition was very inefficient.

3) Porosity within the powder grains also appears to increase volatilization. Metallographic mounting (Fig. 4) made by hot pressing the powders in a copper matrix, showed high porosity in the zirconium carbide. This porosity could account for the low density of the zirconium carbide deposits, i.e., only 80 pct compared to 90 pct for the other carbides and beryllium metal.

The sprayability, or ease of spraying titanium and tantalum carbide, appears to be related to the characteristic of the spray powders. The photomicrographs shown in Fig. 5 show these two powders mounted in copper. Both carbides have grains that appear to be 100 pct dense. Size and shape vary greatly, however. The titanium carbide has sharp, angular grains varying in size from 5 to 40 microns, whereas, tantalum carbide has rounded grains varying in size from 20 to 40 microns. Although both carbides can be easily sprayed, the tantalum carbide has greater sprayability. The uniformity of particle size and the minimum of fine particles in the TaC must account for the improved sprayability, since the melting point of TaC is more than 1100°F higher than titanium carbide.

Summary

This work has shown that facilities can be readily built to control both the toxicity and oxidation problems associated with the plasma spraying of beryllium, beryllium oxide, and various carbides and a nitride. With high quality powders, deposits can be obtained that are at least 90 pct dense, and which are strongly adherent and have high impact resistance.

With this knowledge, it is now important to find new application for plasma spraying, particularly in the aerospace field. Possible uses are as coatings on rocket nozzles, jetavators, and re-entry nose cones of ballistic missile and aerospace gliders. Plasma spraying also provides a means of fabricating structure of single or composite materials that would be nearly impossible to fabricate by other means.

The day of plasma spraying is at hand and greater reliance must be placed on it to help meet the engineer's demand for new, better, and higher temperature materials.

TUNGSTEN FABRICATION BY ARC SPRAYING

This paper is concerned with the development of the plasma-arc spray process for the fabrication of free-standing tungsten bodies and its projection from the laboratory into the production of full-scale hardware.

by R. H. Singleton, E. L. Bolin, and F. W. Carl

The methods presently known and in use for the fabrication of free standing tungsten cylinders and cones are: 1) Cold press and sinter, 2) Hot press, 3) Plasma arc spray, 4) Slip cast and sinter, 5) Arc Melt, 6) Fabricate from sheet, and 7) Forge using preforms made by (1) or (3).

Present known methods of applying tungsten coatings to graphite are: 1) Vapor deposition, 2) Vacuum evaporation, and 3) Plasma arc spray process.

This paper deals mainly with the development of the plasma-arc spray process for the fabrication of free-standing tungsten bodies and its projection from the laboratory into the production of full-scale hardware. In addition, the direct application of tungsten coatings to graphite by the plasma-arc spray process is briefly described.

Spray process

A schematic diagram of a plasma arc spray gun designed and built by Allison is shown in Fig. 1. The unit consists essentially of a tungsten tipped water cooled copper cathode surrounded by, but insulated from, the water-cooled copper body of the gun, which is the anode. A dc arc is struck between the electrodes forming plasma.

Plasma may be defined simply as any gas heated to a sufficiently high temperature so that it becomes ionized and hence electrically conductive. It also glows and emits radiation characteristic of its particular species and temperature. Plasma can be seen in an ordinary welding arc.

The plasma formed by the arc is pushed through an orifice in the front of the gun by the force of the influent gas, which is bled in through the cathode. The influent gas consists of a mixture of argon and nitrogen. The net result is the formation of a plasma jet which emerges from the front of the gun as shown. The tungsten powder to be sprayed is injected into the stream through a tube with the aid of argon carrier gas. The powder thereby becomes suspended in the stream, and is propelled at near sonic velocity onto the work piece to be coated. A powder consisting of agglomerates of particles with an average diameter of 7 microns, as determined by the Fisher Subsieve Sizer Method, has been found satisfactory. The powder particles become molten or nearly molten prior to impact, and upon impact, release their kinetic energy in the form of heat. It may be shown by calculation that this extra impact heat can raise the particle temperature by several hundred degrees depending on the velocity. In order to prevent the substrate from overheating, streams of liquid carbon dioxide or air coolant are directed at the substrate in a direction parallel to the impinging particles. A powder feed rate of 8 lb per hr is used and a material efficiency of 50 to 60 pct is obtained.

A photograph of the gun in operation is shown in Fig. 2. In this particular case, the inside surface of a graphite ring is being coated while turning in a lathe.

Measurements were made of some of the properties of arc-sprayed tungsten and typical data are shown in Table I. Ring specimens ¾-in. ID x 1¼-in. OD x ½ in. long were made by spraying onto a ¾-in. diam steel rod using sodium chloride as parting agent. A cross-sectional photomicrograph of the sprayed material is shown in Fig. 3 where the typical lamellar structure is evident. The density of arc-sprayed tungsten has been shown to vary over the range 85 to 88 pct of theoretical. It has an ultimate tensile strength of about 20,000 psi as determined by the ring crush test.[1] Attempts to hammer forge the small spray formed ring specimens were unsuccessful.

The removable mandrel technique for fabricating free-standing bodies was developed in the laboratory and projected to the production of full scale hardware. Massive pieces of tungsten with wall thicknesses greater than 1 in. and weighing over 100 lb have been produced. The full scale mandrels are permanent in the sense that they can be used to make a number of pieces of hardware. The mandrel is so constructed that cracking of the tungsten during build up is prevented.

In the fabrication of tungsten components for use at high temperatures in physical contact with

Table I. Room Temperature Properties of Tungsten

	Arc Sprayed	Arc Sprayed and Sintered	Cold Pressed and Sintered
Density, pct of theor.	86	93	93
Microstructure	Lamellar	Equiaxed Fine Grain	Equiaxed Fine Grain
Hardness, DPH	250	300	300
Ultimate Tensile Strength,* psi	22,000	70,000	60,000
Forgeability	Poor	Good	Good

* Ring crush test.

R. H. SINGLETON, E. L. BOLIN, and F. W. CARL are with the Allison div., General Motors Corp., Indianapolis, Ind. This paper was presented at the AIME's sponsored sessions of the 1961 Western Metals Congress.

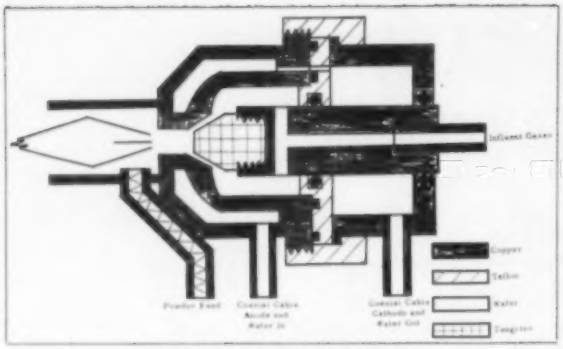


Fig. 1—Allison plasma spray gun.

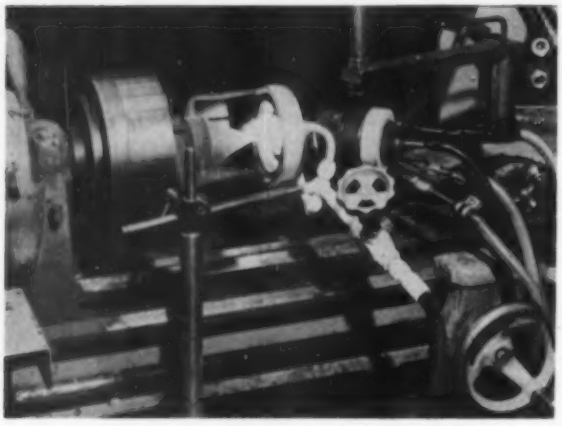


Fig. 2—Plasma arc spray gun in operation.

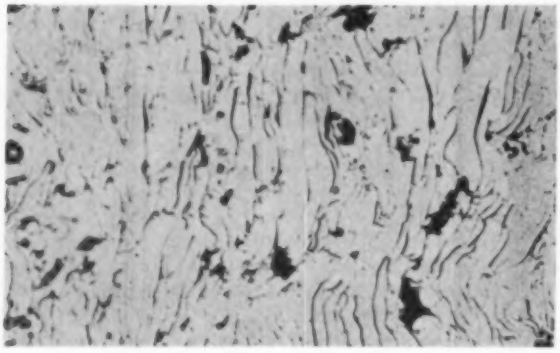


Fig. 3—Plasma arc sprayed tungsten, 500X.

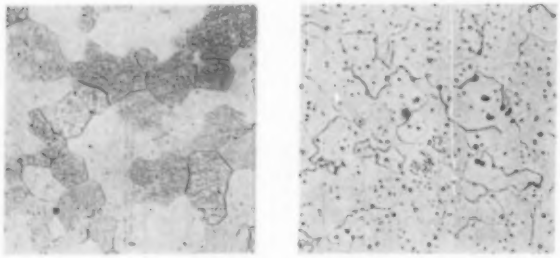


Fig. 4—Left, arc-sprayed and sintered tungsten; right, cold-pressed and sintered tungsten; both 500X, reduced 50 pct for reproduction.

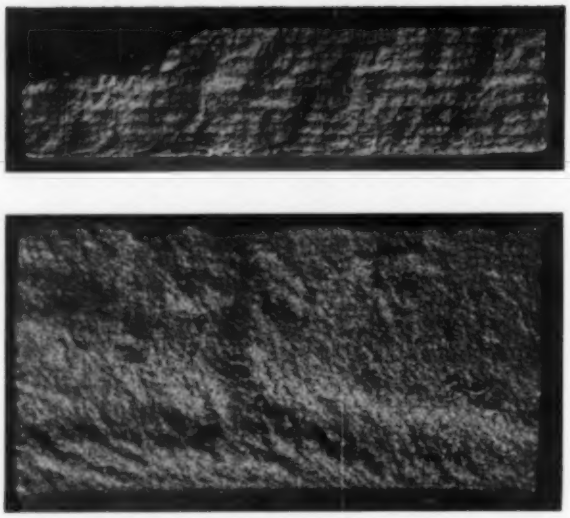


Fig. 5—Factographs of arc-sprayed tungsten: above, before sintering; below, after sintering; both 9X, reduced about 65 pct for reproduction.

graphite, the major advantage of the removable mandrel technique over direct arc-spray coating of the graphite with tungsten is that the properties of the tungsten can be improved by heat treatment without danger of tungsten carbide formation as a result of reaction with the graphite.

Characteristics of sintered product

The free-standing tungsten hardware made by the removable mandrel technique is densified by a sintering-type heat treatment and then machined to final dimension. Complete recrystallization occurs during sintering, resulting in a fine grained equiaxed microstructure as shown in Fig. 4. The structure is very similar to that of cold-pressed and sintered material, the typical microstructure of which is also shown in Fig. 4. The macrostructure of arc-sprayed tungsten both before and after heat treatment is shown in Fig. 5. It should be noticed that the heat treatment removes all traces of the sprayed lamellar structure. This type of structure is due mainly to varying levels of oxygen impurity incurred during the spray operation.

Some room temperature properties of the sprayed material are compared with typical commercial cold-pressed and sintered material in Table I. The properties of cold-pressed and sintered material are seen to be quite similar to those of arc-sprayed and sintered material.

The strength data used in Table I was obtained by the ring crush test method.[1] The forgeability tests were carried out in the laboratory using small rings specimens ¾-in. ID x 1¼-in. OD x ½ in. long prepared by the removable mandrel technique. The specimens were heated and then given a 50 pct upset reduction using a single blow from a 2000-lb drop hammer. Both cold-pressed and sintered and sintered arc-sprayed material forged without internal or edge cracking.

The ductile-brittle transition temperature of sintered arc-sprayed tungsten was determined by means of a simple bend test. Rectangular specimens 1.5 in. x 0.70 in. x 0.05 in. were prepared using a diamond grinding wheel. Bending was accomplished by supporting the specimen at two points

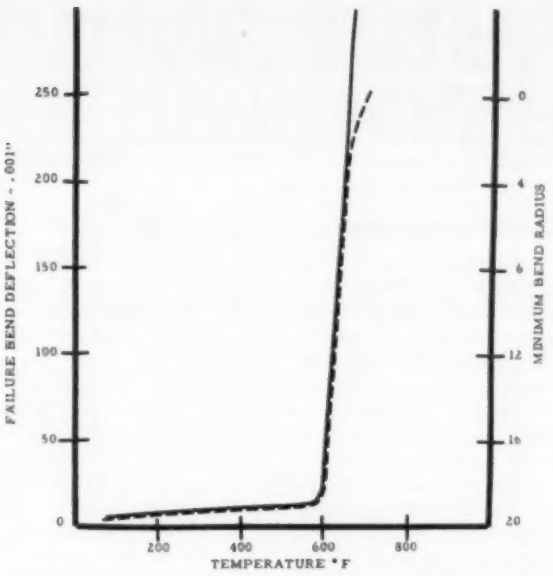


Fig. 6—Effect of temperature on bend ductility of recrystallized tungsten; solid line for arc-sprayed and sintered tungsten, broken line for cold pressed and sintered tungsten.

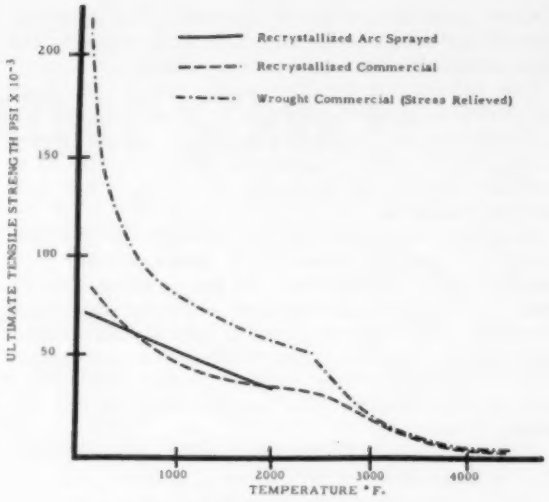


Fig. 7—Tensile properties of tungsten.

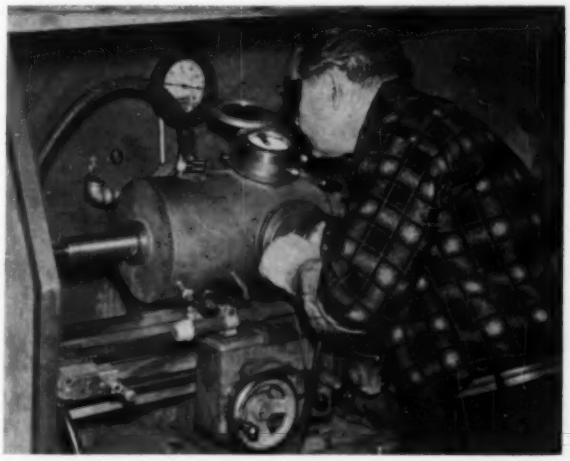


Fig. 8—Inert atmosphere plasma arc spray unit in operation.

by ¼-in. rounds and loading through a ⅛-in. round at the center of a 1 in. span. The load was applied by a tensile machine with a cross-head speed of 0.025 in. per min. The amount of bend deflection required to fail the specimen was indicated by a sudden drop in indicated load. The failure bend deflection is shown in Fig. 6 as a function of temperature. The ductile-brittle transition zone for sintered arc-sprayed tungsten is seen to be 600° to 650°F. For comparative purposes, the bend ductility of commercial wrought and recrystallized tungsten is also plotted in Fig. 7 as a function of temperature.[2] The very close proximity of the ductile-brittle transition zone wth the arc-sprayed material is apparent.

The tensile properties of sintered arc-sprayed tungsten are compared with those of commercial wrought rod and recrystallized commercial wrought rod in Fig. 8. It is apparent that the arc-sprayed material is quite similar to recrystallized commercial wrought rod. The room temperature strength values of the arc-sprayed material were determined by the ring crush test. The values shown at 1000° and 2000°F were obtained by conventional tensile testing using a cross head speed of 0.035 in. per min.

Inert-atmosphere spray process

The inert-atmosphere, plasma-arc spray process is presently under development at Allison. Compared with the conventional method of spraying in air, this process offers the following advantages when spraying tungsten: 1) contamination is decreased markedly, and 2) density is increased.

A photograph of the laboratory unit in operation is shown in Fig. 8. This particular box was built especially for the production of sprayed tungsten specimens for property determination. Cylindrical graphite mandrels may be coated to any desired length. Prior to its operation, the box is evacuated with a mechanical vacuum pump. The gun operating conditions are essentially the same as when spraying in air except that the substrate coolant is

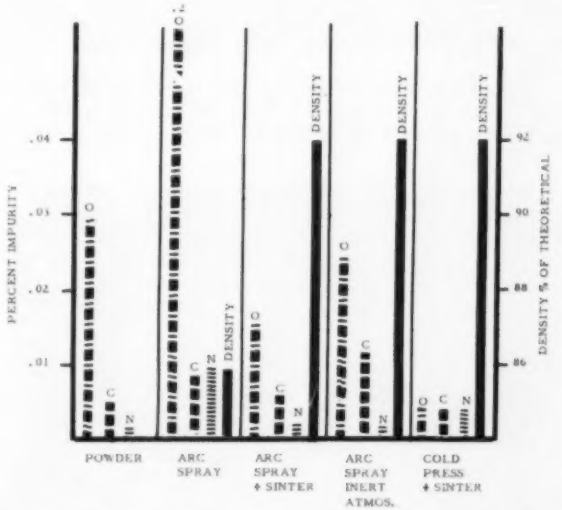


Fig. 9—Typical oxygen, carbon, and nitrogen impurities levels and densities of tungsten.

omitted. During the spray operation, the temperature of the substrate is elevated. This explains the high densities obtained by this process.

The interstitial type impurity content of inert arc-sprayed tungsten is higher than commercial cold-pressed and sintered material, as illustrated in Fig. 9. A study is presently being conducted to further reduce the impurity level in inert arc-sprayed material.

It should be noted in Fig. 9 that the conventional air-sprayed material is contaminated with oxygen and nitrogen. Over 90 pct of these impurities are removed during the sintering operation. However, the impurity level is still slightly higher than commercial tungsten. Studies are now underway to lower the impurity content of arc-sprayed and sintered tungsten by modifications in the sintering procedure.

The density of inert-atmosphere sprayed tungsten is equivalent to conventional sprayed and heat treated material. Studies are presently underway to determine whether the density and purity of the inert-atmosphere sprayed material can be further improved by sintering. Further, the mechanical properties of inert-atmosphere sprayed material are being determined.

A large dry box for the fabrication of large tungsten parts has recently been placed in operation. Spray rates equivalent to standard arc-spray coating are being obtained. At the same time, material efficiency has been increased to 70 to 80 pct. The study of mechanical fabrication problems is continuing and the method looks promising not only as a technique for fabricating free standing tungsten bodies but also as a method for the application of superior tungsten coatings directly to graphite.

Forging arc-sprayed tungsten

It is well known in the art that mechanical working, such as forging, improves the low temperature strength and ductility of tungsten. The hammer forging of arc-sprayed material has been under development for the past 6 months and has resulted in the production of large crack-free tungsten shapes. The forging preforms were made by spraying onto a removable mandrel followed by a sintering type heat treatment. These forged shapes were produced in cooperation with the Taylor Forge Co. of Chicago, Ill.

The microstructure of forged, arc-sprayed tungsten is shown in Fig. 10. This particular material had been given a reduction of 33 pct. Some elongation of the grain is evident. The microhardness was 360 DPH.

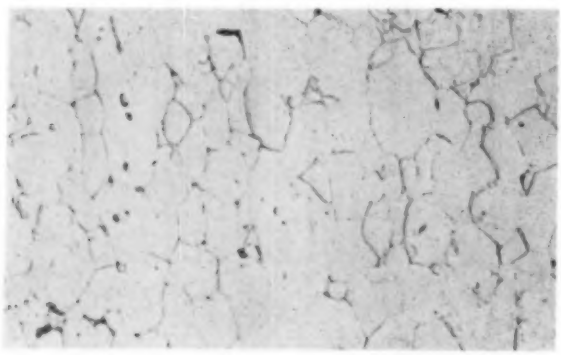


Fig. 10—Plasma arc sprayed and forged tungsten, 500X.

To date, forging has increased the strength of arc-sprayed tungsten but only at the expense of ductility. The ductile-brittle transition temperature has been elevated. Studies are continuing in an attempt to improve the ductility of this material in the low temperature range.

Direct-spray coating of graphite

Tungsten coatings have been applied directly to graphite by the plasma-arc spray process. In applications where tungsten is required next to graphite, direct coating offers the advantages over the removable-mandrel technique in that it is cheaper and that thinner and lighter coatings can be applied. However, reaction of the coating with the graphite backup as well as sinter shrinkage problems prevent the use of sintering as a method of improving coating properties. Hence, the properties of the tungsten coating are somewhat inferior although it is satisfactory in some applications. Coatings up to 0.100 in. thick have been successfully applied to the inside surfaces of hollow graphite cylinders and cones by direct spraying.

The properties of tungsten coatings on graphite can be considerably upgraded by spraying in a dry box and this method should have considerable potential in the application of thin, lightweight coatings to graphite.

Outlook

The arc-spray and sinter technique has been developed at the Allison div. as a new, convenient method of fabricating tungsten shapes. The product has been shown to be generally equivalent to commercial recrystallized material produced by cold pressing and sintering. The arc-spray and sinter technique offers the following advantages:

1) No size limitation;
2) Low tooling cost;
3) Consistency of properties in each piece from mid-radius to edge;
4) Flexibility of contour design; and
5) Simple tooling allows minimum time duration between design change and production of hardware.

It is planned to continue to use the arc-spray forming technique for the production of tungsten and tungsten-base alloy shapes as dictated by the needs of the industry.

The development of tungsten forgings, using sprayed preforms, appears promising and offers the potential advantages of increased strength and toughness. Attempts will be made to improve the ductility of forged material by increasing the purity of the preforms.

Inert-atmosphere spraying offers a means of greatly improving the properties of tungsten coatings laid down on graphite by the direct-spray process. This approach will be developed as a method of applying superior lightweight tungsten coatings to graphite.

References

[1] S. A. Bortz and H. H. Lund: Evaluation of a Tension Test for Brittle Materials, proc. Sixth Annual Carbon Conf., held University of Buffalo, Buffalo, New York, Oct. 1959.

[2] V. D. Barth: Physical and Mechanical Properties of Tungsten and Tungsten Base Alloys, DMIC Report 127, *Battelle Memorial Inst.*, Columbus, Ohio, Mar. 1960.

TANTALUM ALLOYS FOR ELEVATED-TEMPERATURE SERVICE

Early results of a tantalum alloy development program have shown that high hot-strength properties can be attained while maintaining low-temperature toughness and ductility.

by F. F. Schmidt, D. J. Maykuth, and H. R. Ogden

During the past few years, the need for high-temperature structural materials has increased greatly. The refractory metals, tungsten, tantalum, molybdenum, and columbium—in order of decreasing melting point—are considered to be most promising for such components as leading edges, rocket nozzles, and control devices in re-entry type vehicles. A considerable amount of research and development has been conducted in the past few years to study base-line properties of the refractory metals and to improve high-temperature mechanical properties through alloying.

Although the physical, mechanical, and metallurgical properties of tantalum metal were well known, it was not until 1958-59 that investigations of the potential of tantalum as an alloy base for high-temperature service were initiated. The high melting point of tantalum combined with its excellent low-temperature ductility, fabricability, and toughness are its important attributes. Conversely, its high density, poor oxidation behavior and relative scarcity compared to other refractory metals are the major deterrents to the use of tantalum. However, the oxidation behavior of tantalum is similar to the other refractory metals, all of which require protective coatings for high temperatures.

Refractory alloy design considerations can vary greatly depending upon the intended end-use. One approach used in the development of tantalum alloys has been to improve the high-temperature strength properties while maintaining the good fabricability, low-temperature ductility, and weldability characteristics of tantalum. To meet these objectives, the choice of major alloy additions are limited to those elements which have high melting points, similar crystal structure, favorable size fit, low-transition temperature (if possible), and favorable density. These parameters limited alloy element selection to the following: Ti, Zr, Hf,V, Cb, Mo, and W.

Experimental procedures

After alloy selection, button ingots weighing about 150 g were prepared by non-consumable arc melting techniques using electron-beam-melted tantalum as the base material and high-purity alloying elements. Fabrication to sheet was conducted at one of three temperatures—room temperature, 1800°, or 2900°F—depending upon alloy content. Stainless steel and molybdenum packs were used for fabrications at 1800° and 2900°F, respectively. Several alloy compositions exhibited a high capacity for cold work, up to 75 pct, following pack rolling. After determining the 1 hr recrystallization temperature—based on hardness measurements and metallographic examination—tensile specimens were recrystallized and tested in order of preference: 1) 2190°F, 2) room temperature, and 3) over a range of temperatures for promising compositions. Bend ductility tests were also conducted on recrystallized material at room temperature and −320°F.

F. F. SCHMIDT, D. J. MAYKUTH, and H. R. OGDEN are with Battelle Memorial Institute, Columbus, Ohio. This paper was presented at the AIME-sponsored sessions of the 1961 Western Metals Congress.

Results and conclusions

The effect of Group IV-A (Ti, Zr, and Hf), Group V-A (V and Cb), and Group VI-A (Mo and W) elements on the tensile properties of tantalum at room temperature and 2190°F are shown in Figs. 1, 2, and 3, respectively. Titanium, zirconium, and hafnium increase room temperature strength significantly, with peak strengths observed at high alloy contents of about 20 to 40 pct. At 2190°F, strength peaks shift to lower alloy contents—about 10 to 20 pct—with hafnium showing the most potent strengthening effects at the 20 pct level. Also, small additions, 1 pct, of the Group IV-A elements cause sharp strength peaks, apparently through reactivity with interstitial impurities.

Of the Group V-A elements, vanadium is a potent strengthener at both room temperature and 2190°F, while columbium does not alter the base properties significantly. The ineffectiveness of columbium is not surprising, since there is practically no difference in atom size between columbium and tantalum. However, columbium does reduce the density.

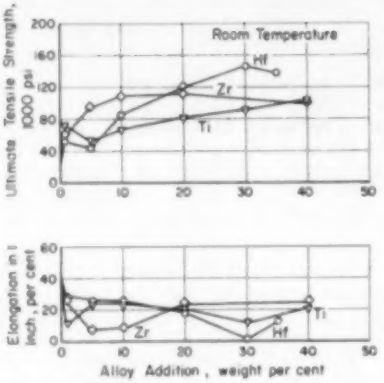
Table I. Room-Temperature Tensile and Bend Properties of Tantalum and Some Ternary Tantalum-Base Alloys

Alloy Composition, wt pct	Ultimate Tensile Strength, 1000 psi	Elongation in 1 in., pct	Minimum Bend Radius, T
100Ta	30.4	42	0
Ta-30Cb-7.5V	139.1	27	0
Ta-10W-5Mo	—	—	>46
Ta-10Hf-5Mo	106.0	3	0
Ta-10Hf-5W	115.3	23	3
Ta-5V-5Mo	133.2	3	0
Ta-10V-5W	—	—	13

Table II. Properties of Tantalum and Selected Tantalum Alloys at −320°F

Alloy Composition, wt pct	Ultimate Tensile Strength, 1000 psi	Elongation in 1 in., pct	Minimum Bend Radius, T
100Ta	101.0	8[a]	0
Ta-30Cb-5V	167.5	26	0
Ta-30Cb-10V	217.0	21	0
Ta-10Hf-5W	—	—	4

[a] Considerable localized necking and reduction in area.



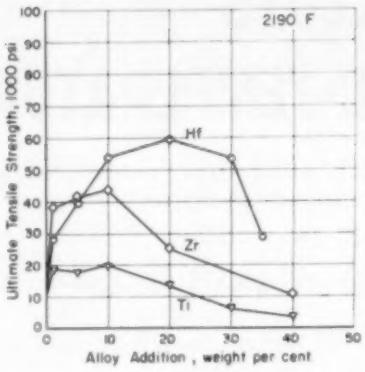
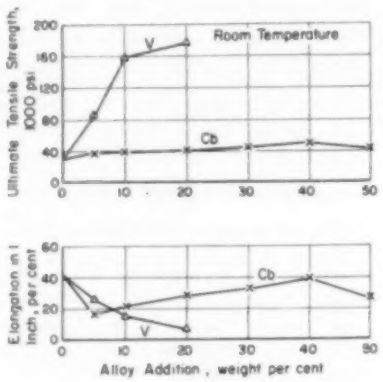


Fig. 1—Left, Tensile properties of tantalum alloys containing Group IV-A Elements.

Fig. 2—Below, Tensile properties of tantalum alloys containing Group V-A elements.



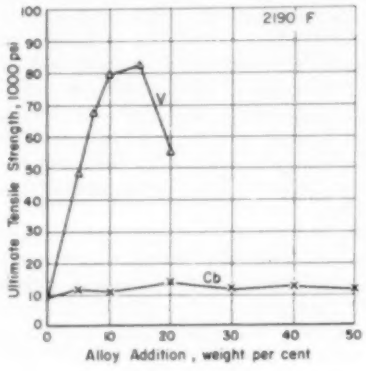
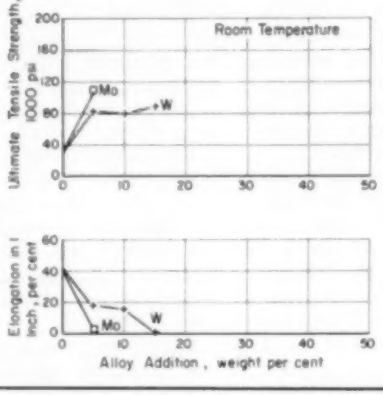
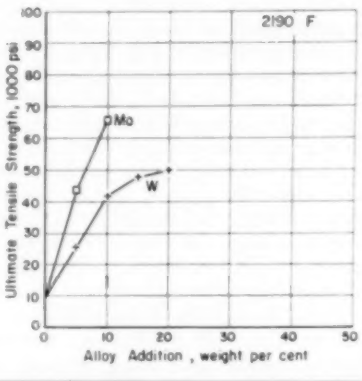


Fig. 3—Right, Tensile properties of tantalum alloys containing Group VI-A elements.





Of the Group VI-A elements, molybdenum and tungsten increase strength significantly, with molybdenum exhibiting the most potent effects. However, molybdenum has a greater detrimental effect on room-temperature ductility and fabricability. Fabrication of good quality sheet has been found to be limited to about 20 pct W and 10 pct Mo.

Table I presents selected room-temperature tensile and bend properties of tantalum and ternary tantalum alloys. At 2190°F, ternary tantalum alloys containing additions from a single periodic group, such as the Ta-10W-5Mo — Ta + Group VI-A, or additions from two periodic groups, such as the Ta-10Hf-5W alloy — Ta + Group IV-A + Group VI-A, exhibit excellent strength levels. As expected, in most cases strengthening appears to be additive. In considering a balance between 2190°F tensile strength and good low-temperature ductility, the Group VI-A elements, molybdenum and tungsten, must be kept at relatively low levels. The best combination of low-temperature ductility and elevated-temperature tensile strength is noted for the Ta-30Cb-7.5V alloy. Furthermore, this alloy has an attractive density of 0.425 lb per cu in., particularly when compared with 0.600 lb per cu in. for unalloyed tantalum.

The effect of vanadium content on the tensile strength of tantalum and the Ta-30Cb alloy from 75° to 3000°F is shown in Figs. 4 and 5, respectively. The strength peak is seen to shift toward lower vanadium contents as the test temperature is increased. The behavior of vanadium appears related to a lowering of alloy melting point with increasing alloy content. Thus, at high temperatures—on the order of 2400°F and above—an alloy with a high vanadium content will be weaker than one with a low vanadium content. It appears that the addition of about 7.5 pct V to either tantalum or the Ta-30Cb alloy gives the best strength properties from 2190° to 3000°F.

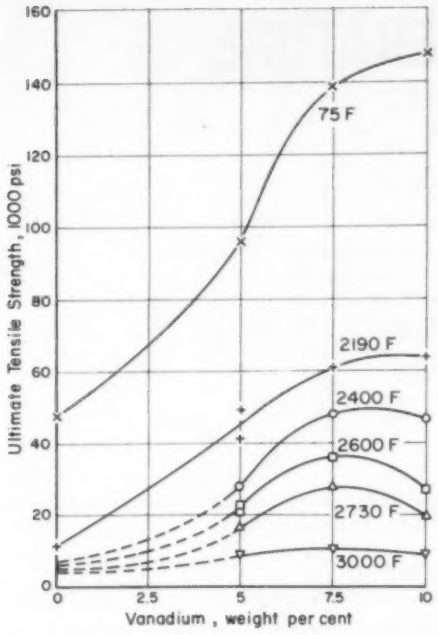


Fig. 4—Left, Effect of vanadium on the elevated-temperature tensile strength of tantalum.

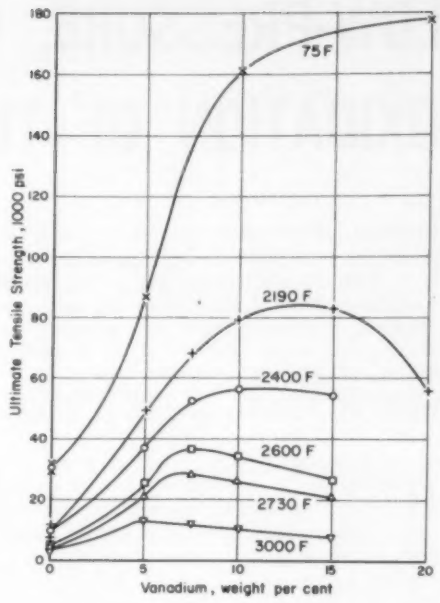


Fig. 5—Right, Effect of vanadium on the elevated-temperature tensile strength of a Ta-30Cb base alloy.

Several of the solid-solution-strengthened alloys of tantalum retain, at least to a considerable degree, the excellent, low-temperature ductility characteristics of tantalum and, at the same time, exhibit severalfold strengthening improvements at high temperatures. As shown in Table II, the low-temperature ductility of the Ta-Cb-V alloys is outstanding, while limited bend data for the Ta-10Hf-5W alloy show little loss in ductility from room temperature to −320°F.

The effect of temperature on the tensile strength and strength:density ratio of several refractory metal alloys is shown in Figs. 6 and 7, respectively. On an equivalent strength basis, both the Ta-30Cb-7.5V and Ta-10Hf-5W alloys are stronger than either F-48 or Mo-0.5Ti. Over the temperature range 2600° to 3000°F, the Ta-10Hf-5W alloy is the strongest of the alloys shown. Above 3000°F, tungsten is stronger. On a strength:density basis, the Ta-30Cb-7.5V alloy exhibits the best strength from 2200° to about 2800°F; from 2800° to about 3100°F the strength advantage shifts to the Ta-10Hf-5W alloy; and above 3100°F, it appears tungsten will be the strongest.

Based on these early results, it is apparent that tantalum alloys with good combinations of high-temperature strength and low-temperature toughness are being developed. Further work is under way to improve existing properties, investigate weldability, scale-up promising candidates, study methods of protecting tantalum alloys from oxidation at high temperatures, and use auxiliary strengthening mechanisms, such as dispersion and aging reactions.

References

[1] M. Semchyschen, G. D. McArdle, and R. Q. Barr: Development of Molybdenum-Base Alloys, Climax Molybdenum Co., contract AF 33(616)-5447, WADC TR 59-280, Oct. 1959.
[2] A. V. Levy and S. E. Bromer: The Development of Refractory Sheet Metal Structure, Marquardt Aircraft Co., Mar. 1959.
[3] Recent Advances in Columbium Alloys, Applied Research Operation, General Electric Co., July 1959.
[4] J. W. Pugh: Tensile and Creep Properties of Tungsten at Elevated Temperatures, *ASTM* Proc., vol. 57, 1957.
[5] R. W. Hall and P. F. Sikora: Tensile Properties of Molybdenum and Tungsten from 2500° to 3700°F, *NASA* memo 3-9-59E, Feb. 1959.

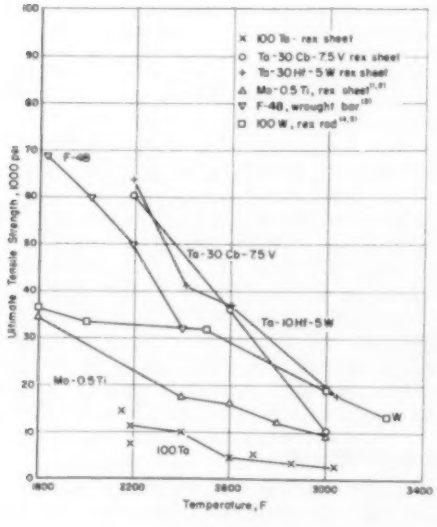


Fig. 6—Left, Effect of temperature on the tensile strength of several refractory metal alloys.

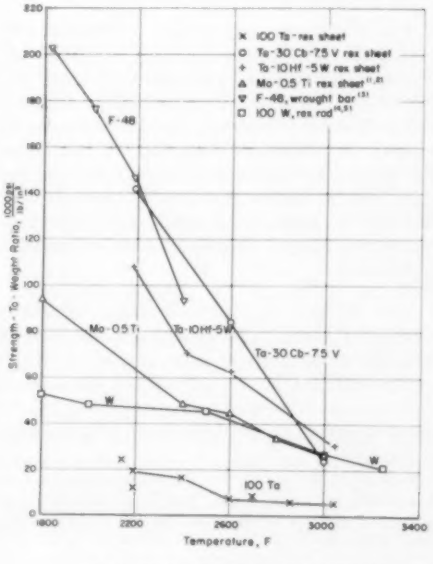


Fig. 7—Right, Effect of temperature on the strength:density ratio of several refractory metal alloys.

LOW-PRESSURE, HIGH-TEMPERATURE OXIDATION OF TUNGSTEN

In many proposed applications, such as high-altitude flight and atmospheric re-entry, components are subjected to high temperatures in air at pressures less than atmospheric. Thus, the oxidation behavior of tungsten in air at pressures from 1 to 40 mm Hg and temperatures from 1300° to 3000°C was studied; the results are summarized in this paper.

by R. A. Perkins and D. D. Crooks

Resistance to oxidation is a major problem in the use of refractory metals and alloys at high temperature. It is generally agreed that these materials must be coated to resist oxidation for extended use at temperatures above 1000°C. While this is true for most conventional applications under normal atmospheric conditions, it should not be accepted as a requirement for all applications. Today, more than ever, materials are developed for an end–item use, and problems must be analyzed in terms of the specific environments anticipated.

In many proposed applications, for example high-altitude flight or atmospheric re-entry, components are subjected to high temperatures in air at pressures less than atmospheric. In a hypothetical glide re-entry trajectory from 400,000 ft, the temperature at the stagnation point on leading edge surfaces may range from 1200° to 2500°C at pressures of 0.01 mm to 500 mm Hg. Under these conditions, a useful materials-life of several minutes to more than an hour may be adequate to complete successfully a mission. Pressures in the interior of a structure are essentially those characteristic of air for a given altitude. But, due to air flow, the outer surfaces of a moving vehicle are subjected to dynamic pressures which are considerably greater. Different materials requirements, therefore, may exist for a given component.

No data on oxidation behavior of refractory metals at temperatures above 1300°C and pressures below atmospheric have been reported. Most data are for temperatures up to 1200°C with a concentration of work at atmospheric pressure and temperatures to 1000°C.[1-3] Results of such tests are not adequate for extrapolation to higher temperatures. Also, with some refractory metals and alloys, a change in oxidation behavior and rate-controlling processes occurs at ultra high temperatures and low pressures.

The oxides of molybdenum, rhenium, and tungsten melt and vaporize at temperatures below the melting point of the base metal. In these cases, the metal surface is not protected by the oxide; hence, the rate of oxidation is controlled by oxygen pressure at any given temperature. Oxidation follows a linear rate law, and the rate increases exponentially with temperature.

R. A. PERKINS and D. D. CROOKS are with Lockheed Missiles and Space Div., Palo Alto, Calif. This paper was presented at the AIME-sponsored sessions of the 1961 Western Metals Congress.

Role of pressure

For most metals forming adherent oxides the effect of pressure on oxidation rates usually is less important than the effect of temperature. However, when volatile oxides are formed, the rate of oxidation depends on the rate of collision of oxygen molecules with the surface. The rate increases with pressure at low pressures. Eventually, at high pressures the surface becomes saturated with oxygen atoms, and the rate becomes independent of pressure. The rate-determining step is dependent on the nth power of the interface concentration of oxygen, and at low pressures it depends on the nth power of the pressure.[8] The linear rate constant is given at low pressures by,

$$K = kp^n \qquad [1]$$

where k is a temperature-dependent function. If the logarithm of the oxidation rate is plotted vs the logarithm of oxygen pressure, the curve will show the following features:

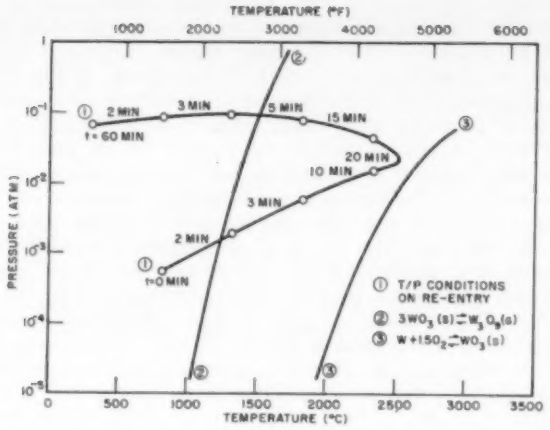
1) at high pressure, the curve is rectilinear and parallel to the pressure axis;
2) as pressure falls, the rate begins to show a pressure dependency; and
3) at low pressures, the curve is rectilinear with a slope of n.

This analysis assumes that oxide vapors are removed continuously from the surface and condensed in cooler portions of the system. Under actual conditions, the rate may be limited by diffusion of oxide from the surface and diffusion of fresh oxygen to the surface.

The temperature at which the oxide evaporates as fast as it forms also is determined by pressure. The equilibrium vapor pressure of WO_3 gas over WO_3 solid as a function of temperature illustrates this behavior (Fig. 1). The temperature at which complete volatilization of the oxide occurs decreases with decreasing pressure. A tungsten structure for the hypothetical re-entry system proposed would be free of oxide during most of the re-entry cycle.

Role of temperature

At any pressure, the rate of oxidation increases exponentially with temperature according to the



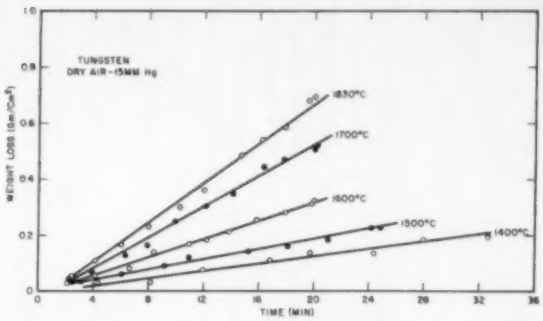


Fig. 1—Left, Relation of Temperature-Pressure-Time conditions during re-entry to tungsten oxidation equilibria. Fig. 2—Right Weight loss vs time for tungsten from 1400° to 1830°C in air at 15 mm Hg pressure.

Ahrennius rate equation:

$$k = Ae^{-\frac{q}{RT}}. \qquad [2]$$

The complete temperature-pressure dependency is described by combining equations [1] and [2]:

$$K = Ae^{-\frac{q}{RT}} p^n. \qquad [3]$$

The rate increases with temperature until the equilibrium temperature for dissociation of the oxide is approached. Oxidation occurs by reversible chemical reaction, and at sufficiently high temperatures, oxides decompose by thermal dissociation.

Oxidation ceases for all practical purposes in some metals, notably silver, palladium, and mercury, when the temperature is raised above that value at which the dissociation pressure of the oxide exceeds that of the atmosphere. The behavior of mercury is of historical significance in that thermal dissociation of mercuric oxide lead to the discovery of oxygen.

For most metals, the oxides are stable to the melting point of the metal. However, free energy calculations indicate that dissociation of the oxides of tungsten, molybdenum, and rhenium occurs at temperatures well below the melting points of these materials. The equilibrium dissociation pressure of WO_3 as a function of temperature is shown in Fig. 1. As the temperature for dissociation at a given pressure is approached, the reverse reaction rate becomes significant, and a change in oxidation behavior occurs. At equilibrium there is no net reaction between tungsten and oxygen, since the forward and reverse reaction rates are equal. The temperature for equilibrium decreases with decreasing pressure, resulting in a broad ultra-high-temperature low-pressure region where low oxidation rates can be anticipated. As the reaction approaches equilibrium, the net loss of metal by oxidation is the difference between the forward and reverse rates. Thus, at any pressure, the net rate first increases, reaches a maximum, and then decreases, approaching zero with increasing temperature.

The reaction of tungsten with oxygen is complex, and the mechanism of oxidation changes significantly with temperature and pressure as follows:

1) at low temperatures, oxide scale forms, and the oxidation rate decreases with time (parabolic rate law);
2) at high temperatures, oxide volatilizes, and the rate of oxidation is constant with time (linear rate law);
3) at very high temperatures, oxide dissociates, and the net rate of metal loss decreases; and
4) the temperature for change in oxidation behavior and the rate for any temperature is pressure dependent.

The oxidation behavior of tungsten in air at pressures from 1 to 40 mm Hg and temperatures from 1300° to 3000°C has been studied to determine the relative effects of these variables on net rate of metal loss, and the results are summarized in this paper.

Experimental studies

Kinetic studies of oxidation were made using a surface recession method. The change in diameter of resistance-heated tungsten rods was measured at 1 to 5 min time intervals. The volume of a cylindrical shell of material removed during the measured time increment was calculated from diameter change. The weight of this volume, divided by the average surface area of the specimen during the time increment, yielded the loss in g per sq cm. The surface recession method for measurement of oxidation permits correction for changing surface area during the course of the experiment. Oxidation rates as measured by this technique were found to be reproducible within ±10 pct at all temperatures and pressures studied.

Tungsten rods 0.1 in. in diam x 7 in. long were heated by direct resistance in a water-cooled vacuum chamber. The rods were fastened to the upper electrode and fitted in the lower base plate to permit expansion and contraction on heating and cooling. A glass port in the side of the furnace permitted direct measurement of both temperature and diameter of the rod throughout the course of the experiments. An index sight point was used for temperature and diameter measurements so that temperature gradients along the length of the rod could be ignored.

Temperature was measured with a micro optical pyrometer calibrated for the system by measurement of the apparent melting point of platinum, iridium, nickel, and molybdenum. The calibration curve compensated for emissivity and sight glass effects. Wire diameter was measured with a filar micrometer eyepiece attached to a telescope—measurements were accurate to ±0.0005 in.

The system was evacuated to less than 1-micron

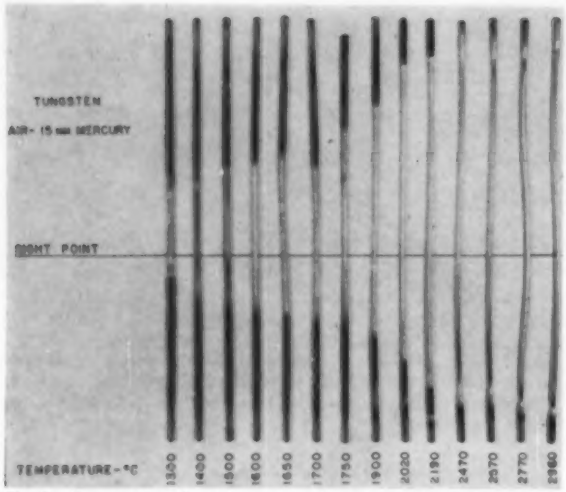


Fig. 3—Appearance of specimens tested in air at 15 mm Hg pressure from 1300° to 2960°C.

pressure, and the rod was heated to the desired test temperature for 5 min before commencing a run. Initial diameter was measured at temperature with the telescope providing a multiplication factor from which actual diameters could be calculated during the course of the test. In testing, an air leak was admitted to an auxiliary chamber directly connected to the vacuum system. The air was dried with a 2½-in. diam x 10-in. high column filled with Linde molecular sieves. Pressure in the reaction chamber was measured by means of a Dubrovin mercury vacuum gage calibrated from 0 to 20 mm Hg pressure and a mercury manometer. The air leak was balanced against the pumping rate to achieve the desired test pressure.

Temperature was controlled during the run by setting the optical pyrometer at the desired test temperature and adjusting the current through the specimen to hold constant temperature at the sight point. Diameter of the specimens was measured every 1 to 5 min for a total time of 20 to 40 min depending upon the rate of metal loss. At the end of the experiment the air leak was closed and the system re-evacuated before cooling to room temperature.

Commercial unalloyed tungsten ground seal rod was used for test specimens. Material was tested in the as-received condition. Each oxidation experiment was made with a new specimen.

Results

At temperatures above 1200°C and pressures from 1 to 40 mm Hg, tungsten oxide was found to volitalize as rapidly as it formed, and the surface remained bright and clean. Surface recession or the net loss in weight per unit area was linear with time at all temperatures and pressures. Typical rate curves from 1400° to 1830°C at 15 mm Hg pressure are shown in Fig. 2. Zero time was taken as the time of admitting the air leak. Since 30 to 60 sec were required to balance pressure and adjust temperature, the rate curves do not extrapolate back through the zero point. Oxidation rates were taken as the slope of the best straight line that could be drawn through the data points.

The appearance of specimens tested in air at 15 mm Hg pressure at temperatures from 1300° to 2960°C is shown in Fig. 3. The darkened ends represent regions at which the temperature was below approximately 1200°C under which conditions an adherent oxide film formed. A significant change in the appearance of the surface occurred at temperatures between 1750° and 1900°C. From 1300° to 1750°C surfaces had a steel gray finish and an etched appearance. Low-power magnification revealed that the attack was not uniform, and the surface was considerably roughened during the course of oxidation. The surface of specimens tested at 1900°C and above was smooth and had a mirror finish similar to that of electro-polished tungsten. As will be shown, the dissociation of tungsten oxide occurs at temperatures above 1750°C. It is believed that redeposition of tungsten on the surface results in the marked change in surface character. The change in surface occurred in tests at all pressures from 1 to 40 mm Hg.

The results of tests at 1, 5, and 15 mm Hg pressure are summarized in Fig. 4. The oxidation rate increased exponentially with temperature from 1300° to 1750°C at all pressure levels. In the range of 1750° to 1900°C, the reverse reaction rate became significant, and dissociation of tungsten oxide vapor resulted in a linear decrease in the net rate of metal loss by oxidation with increasing temperature to 3000°C.

The measured surface recession is interpreted as the result of reaction of tungsten with oxygen at all temperatures and pressures. Since tests were made in air, the possibility of reaction with nitrogen at high temperature was considered. One test in pure nitrogen at 2600°C and 15 mm Hg pressure revealed no measurable reaction.

1300° to 1750°C

A plot of log weight loss vs 1/T is a straight line for tests at 1, 5, and 15 mm Hg pressure. The slope of these lines indicates that the heat of activation according to the Ahrennius rate equation is constant and has a value of 31,500 cal per mol. This compares favorably with the value of 32,500 cal per mol determined for oxidation of tungsten at 750° to 1200°C.[1]

A plot of log rate vs log pressure yields a straight line, indicating a strong pressure dependency for oxidation in this temperature pressure region (Fig. 5). The slope, n, of this line is 0.62 which is in close agreement with a pressure dependency of 0.617 found for the oxidation of molybdenum at 1138°C.[2]

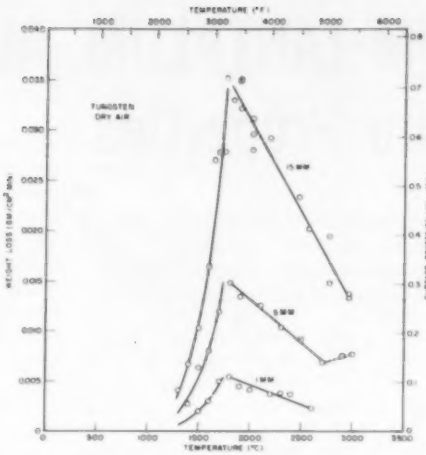
The approximate rate of oxidation of tungsten in air from 1300° to 1750°C at pressures from 1.0 to 40.0 mm Hg can be calculated from equation [3] by using the values of q and n indicated above:

$$K = 14.5e^{\frac{-31500}{RT}} p^{0.62} \text{ g/sq cm/min.}$$

The value of A was determined by solving the equation for each measured value of K. The experimental rate data are within ±10 pct of values calculated from this equation.

1750° to 1900°C

The transition in oxidation behavior between 1750° and 1900°C appears to be a sharply defined break, but it must be studied in more detail to determine the precise behavior. The data indicate that the temperature for maximum rate of metal loss is



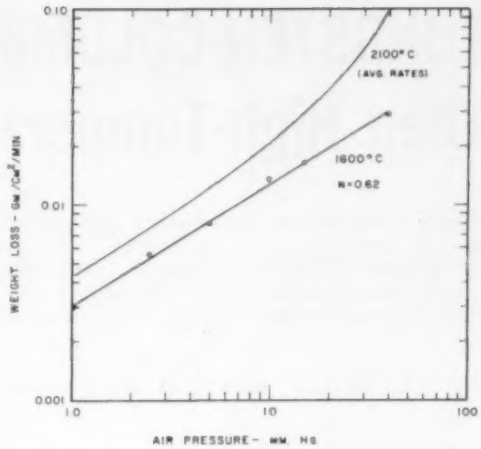


Fig. 4—Left, Rate of weight loss of tungsten in air at 1 to 15 mm Hg pressure from 1300° to 3000°C. Fig. 5—Right, Effect of pressure on oxidation rate at 1600° to 2100°C.

slightly lower at the lower pressures. Maximum rates occurred between 1750° and 1800°C and were 0.0056, 0.0152, and 0.0350 g per sq cm per min for pressures of 1, 5, and 15 mm Hg, respectively. These represent surface recession rates of 0.1, 0.3, and 0.7 mils per min from one side of a sheet. The maximum rate at 15 mm pressure would result in a reduction in thickness of 1.4 mils per min from a tungsten sheet oxidizing from both sides. This is an exceptionally high rate of metal loss and would require protection by coating for exposures beyond several minutes duration. The maximum rate at 1 mm pressure is sufficiently low to permit exposure of uncoated materials for considerable lengths of time. Tungsten sheet exposed for 1 hr at 1760°C and 1 mm pressure would be reduced in thickness by approximately 12 mils.

1900° to 3000°C

The net rate of weight loss by oxidation decreased as a linear function of temperature at temperatures above 1900°C. At pressures below 15 mm Hg and temperatures above about 2700°C, the net weight loss appeared to level off and then increase with increasing temperature. This is believed to be due to volatilization of tungsten metal from the surface and would become more pronounced as pressure is further reduced below 1 mm. The dependency of net weight loss by oxidation on system pressure at temperatures above 1900°C is greater than that observed in tests at temperatures below 1750°C. Log rate vs log pressure is not linear, and pressure dependency increases with increasing pressure (Fig. 5).

Since the measured net loss in weight is the difference between a forward reaction rate (oxidation) and a reverse reaction rate (dissociation), an analysis of the reverse rate is required to determine rate controlling mechanisms for the net change. The pressure of WO_3 vapor at the surface is a rate controlling factor for the reverse reaction. No attempt was made to measure or control this factor, and observations indicated that WO_3 vapor concentration changed markedly with temperature. Rate controlling mechanisms, therefore, cannot be evaluated in this high-temperature region using the present experimental approach. It is believed, however, that factors which affect the concentration of tungsten oxide vapor at the surface have a significant effect on net weight loss by oxidation. Thus, velocity and flow conditions at the surface may be important in oxidation behavior at temperatures above 1900°C.

Changes in surface area and emissivity related to surface roughness and changes in density at high temperatures may have introduced uncontrolled errors in measurement and calculations. An estimate of the correction factors for density change with temperature indicated a small correction well within the scatter band of test results. This factor can be neglected for all practical purposes at this time. Changes in emissivity were compensated for in the initial calibration of the pyrometer. An increase in surface area, due to surface roughening at low temperature, probably introduced the largest error.

Conclusions

Based on the investigations, the following conclusions may be drawn:

1) Tungsten oxide volatilizes as fast as it forms in air at temperatures above 1200°C and pressures of 1 to 40 mm Hg; surfaces remain clean and oxidation obeys a linear rate law;
2) Rate of oxidation from 1300° to 1750°C in air at pressures of 1 to 40 mm Hg can be calculated from the following relation:

$$K = 14.5e^{-\frac{31500}{RT}} p^{0.62} \text{ g/sq cm/min};$$

3) The dissociation of tungsten oxide is important in the oxidation behavior of tungsten at about 1750°C in air at low pressure; the net rate of metal loss by oxidation decreases with increasing temperature above 1750°C due to oxide dissociation;
4) Unalloyed tungsten can be heated in air at pressures below 1.0 mm Hg at all temperatures to its melting point for 1 to 2 hr without excessive surface recession by oxidation; and
5) Oxidation behavior of refractory metals should be analyzed in terms of the specific environment anticipated for a given application; poor resistance to oxidation in normal atmospheres does not preclude consideration for use at high temperatures and reduced pressures.

References

[1] E. A. Gulbranson, K. F. Andrew, P. E. Blackburn, T. P. Copan, and A. Merlin: WADD TR 59-575, *Astia* 236599, Feb. 1960.
[2] North American Aviation Corp., *Astia* 147839, Sept. 1957.
[3] M. G. Cowgill and J. Stringer, *J. Less Common Metals*, vol. 2, 1960, pp. 233-240.

TUNGSTEN-COLUMBIUM-TANTALUM ALLOYS, Their High-Temperature Properties

Alloy compositions blanketing the tungsten-columbium-tantalum ternary system were screened by means of hardness tests at 2300° to 2900°F and weight gain in oxygen at 2190°F. These tests delineated areas combining high hot-hardness with at least tenfold improvement in oxidation resistance over that of pure metals.

by J. L. Wilson and C. R. McKinsey

Tungsten, columbium, and tantalum are prominent members of the rather small group of refractory metals which may serve as base materials for structural applications at high temperatures. Individually, each of these metals has certain merits and deficiencies. Tungsten has the highest melting point and is strongest at elevated temperature, but it has a high ductile-to-brittle transition temperature and the highest density. Columbium has the lowest melting point and the lowest strength at elevated temperature, but it is ductile well below room temperature and has the lowest density. Tantalum is intermediate with respect to melting point, elevated temperature strength, and density, and is the most ductile of the three metals. All share the serious deficiency of poor oxidation resistance at elevated temperatures.

The objective of this investigation was to determine whether solid solutions of tungsten, columbium, and tantalum would provide a better combination of properties than the pure metals for elevated temperature structural applications. Since both mechanical properties and oxidation resistance are of importance, as an initial step, alloy compositions blanketing the ternary system were studied by means of hardness tests in vacuum at temperatures of 2300° to 2900°F and by weight gain in oxygen at 2190°F.

J. L. WILSON and C. R. McKINSEY are with the Metals Research Laboratories of Union Carbide Metals Co., Niagara Falls, N. Y. This paper was presented at the AIME-sponsored sessions of the 1961 Western Metals Congress.

Hardness was determined with a specially-designed apparatus in which the specimen is heated under vacuum by a molybdenum-wound resistance unit. Indentations were made with a sapphire indenter ground in the shape of a standard Vickers pyramid. A 1-kg load was applied for 10 sec at temperatures of 2300°, 2500°, 2700°, and 2900°F. The sapphire indenter, oriented so that its slip plane was perpendicular to the applied load, performed satisfactorily within this temperature range. The hardness impressions were measured with a standard Vickers optical unit at room temperature and, in most cases, were quite distinct throughout the entire temperature range. The accuracy of the measurements decreased appreciably above about 200 VHN because of the small size of the 1-kg impressions.

Alloy compositions were prepared as small buttons melted by the non-consumable electrode arc technique under argon. Specimens were sectioned from the buttons, polished, and tested in the as-cast condition. Hardness impressions were made during the heating cycle. Preliminary tests indicated, as expected, that as-cast hardness would be a reasonably reliable index of elevated temperature strength within the temperature range of interest.

In Fig. 1, the as-cast hardness is compared with the ultimate tensile strength of wrought, recrystallized tungsten, tantalum, and columbium. The hot-hardness of the metals was in the same order as the tensile strength; i.e., tungsten was the hardest and strongest while columbium was the softest and

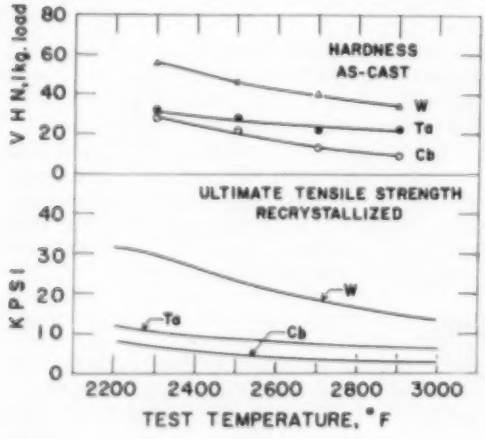


Fig. 1—Left, hot-hardness and tensile strength of pure metals.

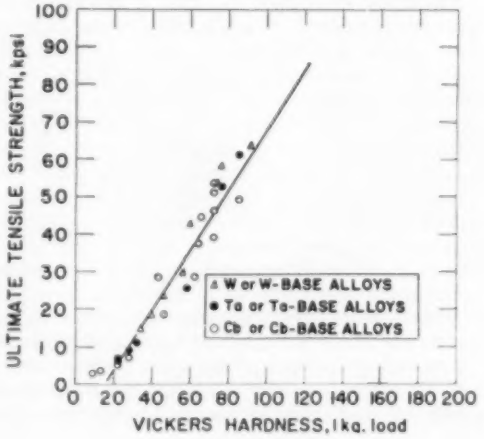


Fig. 2—Right, correlation of hot-hardness and ultimate tensile strength for the temperature range of 2000° to 2900°F.

weakest. Furthermore, the hardness and tensile strength of each metal decreased in a similar manner with increasing temperature.

A correlation of hot-hardness and ultimate tensile strength is shown in Fig. 2 for tungsten, tantalum, columbium, and several of their alloys. Even though the processing history of the hardness specimen and tensile specimen was not always identical, the correlation is quite reasonable.

Figs. 3, 4, and 5 illustrate the hardness results obtained with the three binary systems. Except at 80 atomic pct tantalum, the hardness of the columbium-tantalum alloys was no greater than that of unalloyed tantalum at temperatures of 2500° to 2900°F (Fig. 3). However, marked hardening was observed at 2700° and 2900°F in both the columbium-tungsten and tantalum-tungsten binary systems between about 10 and 90 atomic pct tungsten (Figs. 4 and 5). Maximum hardness occurred in each system at about a 1:1 atom ratio. At 2300° and 2500°F, the trend was the same, but the hardness values were much higher.

Figs. 6 and 7 are ternary sections showing the hardness at 2700°F and 2900°F as a function of composition in atomic pct. At 2700°F (Fig. 6), much of the ternary diagram is occupied by the region of greater than 100 VHN. At 2900°F (Fig. 7), that region is considerably smaller and is shifted toward the tantalum-tungsten side of the diagram. The largest area is now that which lies between 50 and 100 VHN, with most of the values exceeding 75 VHN. At both temperatures, hardness is primarily a function of tungsten content, with columbium: tantalum ratio of secondary importance. Hardness values two to three times that of unalloyed tungsten are common.

Oxidation results

Oxidation resistance was evaluated by recording autographically the weight gain as a function of time in an atmosphere of flowing oxygen. Rectangular specimens cut from arc-cast buttons were suspended inside a Mullite tube heated by a platinum-wound resistance furnace.

Fig. 8 shows the weight gain after 4 hr at 2190°F as a function of composition in atomic pct. At this temperature the values for the pure metals are of the order of 1000 mg per sq cm. There are large areas within the ternary system in which oxidation resistance is improved more than tenfold over that of the pure metals. Compositional ranges in which improvement is less than tenfold (hatched) occur as fairly small regions in the columbium and tungsten corners, and in a large area covering compositions which are rich in tantalum and lean in tungsten.

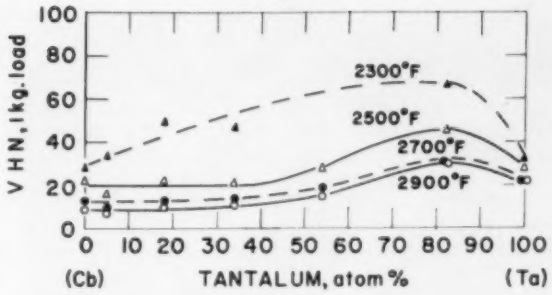


Fig. 3—Hot-hardness of columbium-tantalum binary alloys.

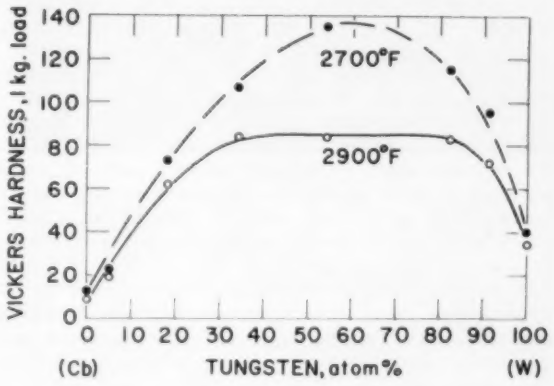
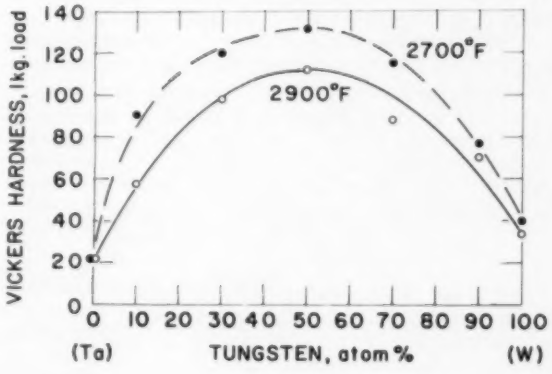


Fig. 4—Above, hot-hardness of columbium-tungsten binary alloys.

Fig. 5—Below, hot-hardness of tantalum-tungsten binary alloys.



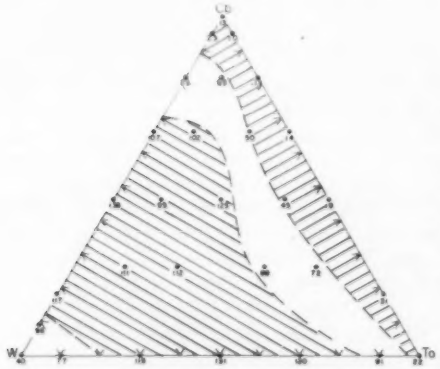
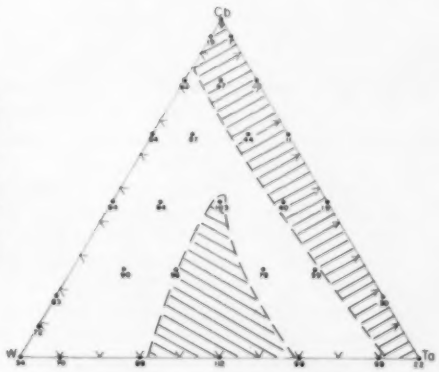


Fig. 6—Left, hardness of tungsten-columbium-tantalum alloys at 2700°F. Fig. 7—Right, hardness of tungsten-columbium-tantalum alloys at 2900°F. Compositions in atomic pct. Cross hatch shows areas < 50 VHN and > 100 VHN.



The variation in oxidation resistance with composition suggests that complex oxides which are more protective than the pure metal oxides may be formed within the ternary system. This viewpoint is supported by kinetic data which showed that oxidation rates within the preferred region were parabolic, typical for a protective oxide and a diffusion-controlled oxidation reaction.

Although the WO_3-Ta_2O_5-Cb_2O_5 system has not been studied in detail, Goldschmidt[1] recently published approximate phase relations in the WO_3-Cb_2O_5 and Ta_2O_5-Cb_2O_5 binary systems. An intermediate phase was found in the former system at approximately $Cb_2O_5 \cdot 3\ WO_3$. Wlodek[2] previously reported a single-phase oxide within the molar ratios 2 $Cb_2O_5 \cdot WO_3$ and $Cb_2O_5 \cdot 2\ WO_3$; so, it is apparent that at least one intermediate oxide exists within the compositional range in which improved oxidation resistance was found in the present investigation. While Goldschmidt did not find an intermediate phase in the Ta_2O_5-Cb_2O_5 system, he reported extensive solid solubility of Cb_2O_5 in Ta_2O_5 and very limited solubility of Ta_2O_5 in Cb_2O_5. The extent of the terminal solid solutions coincided well with the areas of poorest oxidation resistance in the tantalum-columbium binary system (Fig. 8). A single-phase oxide was found in the Ta_2O_5-WO_3 system at a molar ratio of 1.4 $Ta_2O_5 \cdot WO_3$[3], and it is likely that the single-phase region extends to lower Ta:W ratios. Thus, there is evidence that complex oxides may be largely responsible for the observed improvement in oxidation resistance within the W-Cb-Ta system.

Tensile properties

Hot-hardness data at 2900°F are correlated with the oxidation results at 2190°F in Fig. 9. Compositions are plotted in weight pct, rather than atomic pct, which has the effect of shifting the various areas toward the tantalum-tungsten side of the diagram when compared with Figs. 7 and 8.

Alloys selected for a study of tensile properties at elevated temperature are indicated on the diagram. These compositions lie within the area of improved oxidation resistance, but they represent a considerable variation in hot-hardness. The first tensile data available are for the four alloys having the highest columbium content. These compositions were processed to small-diameter rod by impact extrusion followed by hot-swaging. Specimens were tested at 2900°F in vacuum, with the results shown in Table I.

These data indicate a consistent increase in strength with increasing tungsten content, as predicted from the hot-hardness results.

Summary

Screening tests have delineated areas within the tungsten-columbium-tantalum system which combine a tenfold improvement in oxidation resistance at 2190°F with up to a threefold increase in hardness over that of unalloyed tungsten at 2900°F. Preliminary tensile data confirm the strengthening effects suggested by the hot-hardness results. Additional data on fabricability, ductile-to-brittle transition temperature, etc., are necessary to assess fully the utility of these compositions for elevated temperature structural applications.

Certain alloys in this system might be considered as a solid solution base for further development. For example, compositions in the columbium-rich corner having a tensile strength equivalent to, or somewhat greater than, unalloyed tungsten at 2900°F will be likely to have a lower transition temperature than tungsten. Further strengthening by a different mechanism, such as dispersion hardening, may be possible without excessive detriment to ductility. Perhaps it is in this respect that the tungsten-columbium-tantalum alloys will prove most useful.

References

[1] H. N. Goldschmidt: An X-Ray Investigation of Systems Between Niobium Pentoxide and Certain Additional Oxides, *Metallurgia*, vol. 62, 1960, p. 241.
[2] S. T. Wlodek: Oxidation of Cb-Al-V and Cb-Ti-W Alloys, presented at *AIME* Columbium Metallurgy Sym., Hotel Sagamore, Bolton Landing, N. Y., June 9-10, 1960.
[3] Union Carbide Metals Co., Met. Res. Lab., unpublished data.

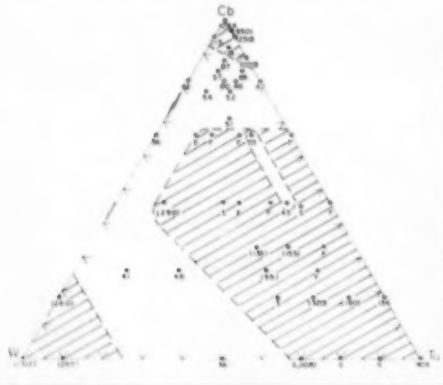


Fig. 8—Left, weight gain (mg/cm sq) of tungsten-columbium-tantalum alloys after 4 hr in oxygen at 2190°F; ( ) extrapolated data, S spalling, and F very fast rate.

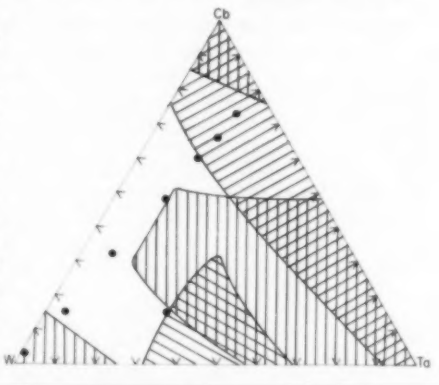


Fig. 9—Right, correlation of hot-hardness and oxidation resistance for tungsten-columbium-tantalum alloys. Vertical shading for inferior oxidation resistance at 2190°F; shading (/) < 50 VHN at 2900°F; opposite > 100 VHN. • Alloys prepared for tensile studies.

Table I. Tensile Properties of Tungsten-Columbium-Tantalum Alloys at 2900°F

Nominal Composition, wt pct			0.2 pct Yield Strength, kpsi	Ultimate Tensile Strength, kpsi	Elong. in 1 in., pct	Red. Area, pct	Estd Hardness at 2900°F, VHN
Cb	Ta	W					
73	18	9	12.9	14.1	50	90	28
66	17	17	14.7	15.7	37	79	46
60	15	25	N.D.[a]	29.0	38	86	50
48	13	39	27.1	35.1	39	38	87

[a] Not determined.

BLAST FURNACES, COKE OVENS, AND LIBERTY BELLS!

A review of the 1961 conferences of the National Open Hearth Steel Committee and the Blast Furnace, Coke Oven, and Raw Materials Committee, which were held simultaneously in Philadelphia April 10-21.

A significant cross-section of the iron and steel industries of the United States as well as Canada, Mexico, and a number of countries of western Europe was evident in the presentation of some 80 papers and panel discussions at Philadelphia's Sheraton Hotel; the occasion was the Forty-Fourth Conference of the National Open Hearth Steel Committee and the Blast Furnace, Coke Oven, and Raw Materials Committee.

The major social event of the conference was the Annual Fellowship Dinner held in the ballroom of the Sheraton Hotel on Tuesday evening, April 11. Principal speaker was Admiral Arthur W. Radford, former chairman of the Joint Chiefs of Staff. Toastmaster of the evening was C. Thompson Stott, general manager, Sparrows Point plant, Bethlehem Steel Co.

Presentations of awards were made by the chairmen of three committees of the Iron and Steel Division. Arthur B. Wilder, chairman of the Acid Converter and Basic Oxygen Steel Committee, presented the committee's Annual Award to G. M. Yocom of Wheeling Steel Corp. The award, described on p. 278 of the April issue of JOURNAL OF METALS, reads, "In recognition of his accomplishments in improving the quality of acid bessemer steel when the need was paramount, his activities in other phases of steelmaking, and his generous contribution to technical societies".

James Chisholm, chairman of the Blast Furnace, Coke Oven, and Raw Materials Committee, next took the rostrum. Awards for quality papers and contributions to the art of iron-making were not made at this conference due to a change in the structure of the Committee's awards, as described on p. 277 of the April issue of JOURNAL OF METALS. However, an award was presented, in absentia, to Miss Katharine S. Lovell, "In grateful appreciation for her many years of service in editing Annual Conference Proceedings of the Blast Furnace, Coke Oven, and Raw Materials Committee . . . and her continued services in editing proceedings of the National Open Hearth Steel Committee . . . and of the Electric Furnace Committee . . .". Miss Lovell, who was for many years assistant editor of *Technologys,* retired from AIME in 1947. She has been assistant editor of the three proceedings volumes, which are edited by E. J. Kennedy, Jr., since the early 1940's. Miss Lovell's certificate, signed by the chairmen of the three committees, was accompanied by an honorarium of $600.

L. W. Moore, chairman of the National Open Hearth Steel Committee made two presentations. The first of these was the Frank B. McKune Memorial Award to Thomas D. Moore of Armco Steel Corp., Middletown, Ohio, for the paper, *Bath Temperature Control on Roof Lance Furnaces.* This paper was summarized in the November 1960 issue of JOURNAL OF METALS, p. 882. Winner of the Open Hearth Conference Award—also for a distinguished paper—was F. P. Johnson of the Indiana Harbor Works of Inland Steel Co. His paper was entitled, *Effect of Increased Open Hearth Productivity on Auxiliary Equipment.*

Open hearth sessions

A number of papers from the two conferences have been, and will be, published in the JOURNAL OF METALS. All of them, together with the discussions, will be included in detail in the proceedings of the two conferences, which will be available later in the year. However, attention should be called to several papers which (unfortunately) cannot be published in full in the JOURNAL OF METALS because of lack of space.

E. Dyble and G. Taylor of the Erie Forge & Steel Corp. described *Deoxidation by Vacuum,* pointing out that the deoxidizing power of carbon at low pressures has been known for many years. However, deoxidation of large heats, using steam degassing facilities, had not been achieved in the U. S. until September 1959. Initial experiments were conducted under intentionally unfavorable conditions which would ordinarily have resulted in a large quantity of indigenous inclusions. The results were gratifying

and led to the subsequent production of heats poured under more favorable conditions.

Conventional melting furnaces are used with an allowance made for the loss of about 0.05 pct C during pouring. No metallic deoxidizers are added, for deoxidation occurs by the reaction of the carbon in the steel with dissolved oxygen. The reaction is killed as soon as possible by a fast pouring rate. During the pouring of the ingot, pressure in the 17-ft diam x 29-ft high vacuum chamber is maintained at 500 to 800 microns. The ingot is permitted to solidify under normal conditions after removing the upper section of the vacuum chamber.

Results have shown that the elimination of metallic deoxidizers results in a reduction in the quantity of non-metallic inclusions. In addition, vacuum deoxidation results in a reduction of oxygen content to the level of 15 to 25 ppm, hydrogen to 0.7 to 0.8 ppm, and nitrogen to low levels. A better distribution of sulfide inclusions is achieved, as well as an improvement in the segregation pattern and magnetic permeability.

Metallurgical problems involved in the production of large ingots for rolling into heavy coils of strip was the subject of several papers. One of these —*Metallurgical Aspects of the Manufacture of Large Rimming Ingots* by B. W. Bowen of Republic Steel Corp.—concerned segregation characteristics encountered when increasing pouring height to 92 in., thickness to 34 in. and width to 81 in. The increase in total segregation which resulted from this enlargement of ingot size was anticipated, but the extent and location of areas of maximum segregation could only be estimated from previous experience and published data on the effect of increased ingot thickness. Extensive segregation was found in the lower portion of the ingot which extended in a thick section up the center plane, especially above 65 pct of the ingot height.

One means of reducing the heavier segregation in the area between 75 and 90 pct of the ingot height is to chemically-cap with aluminum shot. Other factors can be controlled to keep segregation of metalloids within normal bounds. In the furnace, a sharply worked heat during the last hour before tap is more desirable than one delayed for reasons of sulfur elimination or temperature regulation. Delay and excessive working during this period tend to produce a gassy heat. Tap temperature should be fairly hot, and sulfur should be kept low.

Ladle deoxidation with aluminum can be designed to obtain a brisk, but not violent, rimming action in the mold. In the Cleveland shop of Republic Steel —due to a high pouring rate and ingot height—from ¾ to 1 lb per ton of aluminum is normally added to the ladle, depending on slag FeO and other conditions.

To avoid the more violent rimming action associated with cold molds, and the weak gas evolution often encountered when molds are hot, teeming is done in warm molds in the 150° to 300°F range. A flux is used, and aluminum shot, preferably ¾ to 1¼ oz per ton, is added as needed. Normal capping by means of sheet steel *plating* plus water cooling is employed. Practice is to strip the ingot fairly early and deliver it to the soaking pit in 2¾ to 3 hr. Too fast a delivery, in combination with rapid firing and short *soak*, can produce heavy center segregation below 50 pct ingot height. An extreme condition of this kind can result in sufficient gas being retained in the central portion of the ingot to *blister* the slab after rolling.

G. M. Yocom receives the Acid Converter and Basic Oxygen Steel Committee Award from Arthur B. Wilder (right).

L. R. Walker, J. O. Mack, and J. F. Georgiadis of the Fairless Works of U. S. Steel Corp. discussed *The Adaption of Large Mechanically-Capped Ingots to Cold Rolled Sheet Applications.* The authors pointed out that a decrease in the heat time and an increase in the heat size of the plant's open-hearth furnaces provided an impetus for increasing ingot sizes. Most of the big-end-down, open-top, and bottle-top molds have been increased in height, and some have also been increased in cross-sectional area. These changes were preceded by trials and evaluations to assure that steel quality would not be affected adversely.

One of the fundamental concerns was segregation. To evaluate segregation in large capped ingots, two experimental 38x43x111-in. molds were placed adjacent to two 27x42x90-in molds for a heat of low-carbon steel. One of each of these two sizes was selected for the segregation evaluation based on the closest conformity to the optimum metallurgical standard practices. The heights of the peaks for manganese, phosphorus, and sulfur were only slightly higher in all instances in the large ingot However, the peak for carbon in the large mold was appreciably higher than in the small mold. But a sizable quantity of sheet and tin products was produced from the experimental 38x43x111-in. mold with only a few problems which were satisfactorily overcome by means of changes in operating practices. Consequently, the difference in the magnitude of carbon segregation between the two ingots was assumed to be within the workable tolerances.

Another important consideration in the use of this large capped mold was the thickness of the skin on the ingot; however, these large ingots exhibited good skin thicknesses throughout. The use of sodium fluoride to nucleate a good rimming action at the bottom promoted early rimming action, which, when followed by the relatively slow rate of rise in the molds (due to the large cross section), assisted in the formation of thick skins.

The higher incidence of scabs on the surface of slabs from the 38x43x111-in. molds was of great concern. These scabs were primarily associated with the bottom of the ingot where the opening surge from the ladle splashed the mold walls. A sheet metal boot was developed which markedly decreased scab incidence. Investigation showed that a good mold coating was also necessary.

BANQUETS AND AWARDS

Above, Blast Furnace, Coke Oven, and Raw Materials Luncheon.

Below, Thomas D. Moore receives the Frank B. McKune Memorial Award from L. W. Moore (left).

Above, J. S. McMahan receives the award for Miss Katherine Lovell from James Chisholm (right).

Below, to the past chairman of the National Open Hearth Steel Committee, D. R. Loughrey (right), from the chairman, L. W. Moore.

Above, To the past chairman of the Blast Furnace, Coke Oven, and Raw Materials Committee, Robert E. Powers (right), from the chairman, James Chisholm.

Below, F. P. Johnson (right) receives the Open Hearth Conference Award from L. W. Moore.

Slabs rolled from the large cross section ingots exhibited much less tendency to develop cracks and tears on the surface. The large capped ingot is now used on nearly all tinplate applications. All of the capped steel hot-rolled and cold-rolled sheet applications of appropriate widths are also obtained from the 38x44x115 in. and 35x39x115 in. molds. After several years of service, no quality problems associated specifically with the large ingot remain.

Blast furnace sessions

A feature of the blast furnace sessions was a panel discussion on *Carbonaceous Fuel Additives to the Blast Furnace Hot Blast*. Articles on this subject

were presented in the January issue of JOURNAL OF METALS, and publication of information on fuel-oil injection experiments at Dominion Foundries and Steel Ltd. is expected in a future issue.

Use of Blast-Furnace Probes was the subject of a paper by J. C. Agarwal, H. R. Pratt, and R. H. White of U. S. Steel Corp. The authors pointed out that the task of developing blast-furnace technology is doubly difficult because of the nonuniformity existing within the blast furnace and the lack of adequate instrumentation. The gas temperature, composition, and flow profiles across the stack are not uniform, and changes in these profiles greatly alter the thermal conditions in the furnace, thereby affecting the quantity and quality of the iron produced. Sampling the gas with a probe at various points across the stack diameter should indicate the shape of these profiles and show how they are affected by wind rate, hot-blast temperature, charging sequence, and blast additives. Therefore a probe was designed for taking gas samples, as well as temperature and pressure measurements across the diameter of the stack. This probe was installed at the US Bureau of Mines experimental blast furnace at Bruceton, Pa.

Once a backlog of probe data on a given furnace has been collected and historically analyzed with respect to what happened, it should be possible to foresee some of the operating results associated with conditions existing in the stack at any given time. But a new technique was also developed for analyzing the probe data. By knowing the wind rate, the gas composition at the top of the stack, and the feed rate of iron-bearing material, as well as the average gas composition and temperature at the probe level, it is possible—by making appropriate material balances around the furnace and the probe location—to calculate the percent reduction at probe level, the rate of oxygen removal up to the probe level, and the approach to equilibrium for the reduction of FeO to Fe.

Probes have now been installed on the No. 2 blast furnace at Fairless works, but thus far the activity has been experimental, with most of the work centered on the development of an adequate probe and probe-driving mechanism.

Bench-Scale Experiments in Developing Anthracite Metallurgical Briquets was the subject of a paper by W. S. Sanner, R. E. McKeever, and J. W. Eckerd of the Anthracite Research Center of the US Bureau of Mines, Schuylkill Haven, Pa. The authors pointed out that the major objection to the use of anthracite is its inability to retain its shape and size while traveling through the stock columns of modern blast furnaces and cupolas. To improve the performance of anthracite, a study was begun to reconstitute it in the form of an agglomerate fuel having the physical strength of metallurgical coke.

Bench-scale experiments by the Federal Bureau of Mines determined the combination of raw materials, briquetting pressures, and calcining temperatures required to produce briquets highly resistant to impact and abrasion. The binders studied included coal-tar pitches, heavy petroleum residues, bituminous coals, and sulfite liquors. Briquets prepared in the laboratory at pressures of 3000 psi, containing 8 pct coal-tar pitch, 10 pct bituminous coal, and 82 pct anthracite, and calcined at 1750°F were superior to premium furnace and foundry cokes in resistance to impact and abrasion, as determined by the ASTM Tumbler Test for Coke. A calcined briquet with impact and abrasion resistance exceeding that of coke was also produced from anthracite, bituminous coal, and a petroleum-pitch binder. The size of the bituminous coal is not a limiting factor if it does not exceed 20-mesh. The optimum anthracite particle size is 40x80 mesh, and both commercial buckwheat No. 5 and flotation anthrafines are within this range.

R. G. Thompson, R. L. Franklin, J. R. Guseman, and D. E. Rohaus of U.S. Steel Corp. presented a paper on the *United States Steel Hot-Ore Briqueting Process*, describing a newly-developed briqueting process for producing a strong, dense agglomerate for the open hearth from finely-divided ores. The following requirements were established for the agglomerate; 1) it should contain at least 65 pct iron, 2) contain less than 2 pct silica, 3) have a maximum 2 or 3 pct loss on ignition, and 4) have a charging-box density of at least 140 lb per cu ft.

In the process, high-grade hematite fines—approximately-¼ in. in size—are converted to hard, dense briquets by heating to temperatures of 1500° to 1900°F in a rotary kiln and briqueting in a specially-designed roll-type briqueting press. The results of extensive testing at the 25-tpd pilot plant indicated that the most important single variable affecting briquet quality was the temperature at which the ore was briqueted. The specific gravity, the bulk density, and the strength of the briquets were found to increase as the temperature increased. The attainable specific gravity for the briquets corresponded closely to the specific gravity of the natural ore lumps, and thus indicated that a high degree of compaction of ore particles was obtained in the briqueting process. Chemical analysis indicated that the briquets met the minimum iron requirements as well as the maximum silica content. Ignition losses were found to be approximately 0.25 pct, and densities of better than 140 lb per cu ft were attained.

To determine the suitability of the briquets as an open-hearth charging ore, actual open-hearth tests were run; the briquets proved to be a very satisfactory substitute for natural ores, and were found to be superior to sintered charges. Laboratory tests indicated that the briquets may be suitable for blast-furnace operations. A preliminary economic investigation indicated that hot-ore briqueting should be competitive with sintering and pelletizing as a commercial agglomeration technique.

Plant trip

Providing a breathing spell from the technical sessions was the plant trip on Wednesday, April 12. Through courtesy of Bethlehem Steel Co., an inspection trip was arranged to the Sparrows Point plant. Registrants had the opportunity of visiting either the No. 4 open hearth shop, new soaking pits, and blooming mill, or the sintering plant, coke ovens, and blast furnaces. A special train carried visitors from Philadelphia to the plant near Baltimore. Lunch was served by courtesy of Bethlehem Steel Co.

So, filled with new technological ideas, the spirit of renewed friendships, and the smell of steel mills and blast furnaces, some of the registrants of the two conferences wended their way home. But quite a number—still hungering for knowledge—stayed on for the First International Symposium on Agglomeration, scheduled to open the following morning. We shall report on that meeting in a future issue.

HISTORY OF THE COKING INDUSTRY IN THE UNITED STATES

Part IV

This month's installment continues with the history of the emergence of by-product coking in the United States.

by C. S. Finney and John Mitchell

The growing popularity in the United States of the vertical-flue oven was emphasized when in 1905 the United States Steel Corp. chose the Koppers oven as the type which best suited their requirements. Heinrich Koppers was born on November 23, 1872, at a small farm in Walbeck near Geldern on the lower Rhine. When young Koppers was eight years old, however, the family moved away from the farm to the industrial city of Bochum in the Ruhr. Here Koppers attended public school and subsequently served an apprenticeship to a tinsmith before taking a job as a lathe operator with a local steel company. He had ambitions to be much more than a machinist, however, and used his week-ends and evenings to improve his theoretical background by taking courses at a vocational-training school in Bochum. After winning the highest honor the school could bestow (the silver *Staatsmedaille*), Koppers went on to continue his education at the Rheinisch-Westfälische Hüttenschule in Duisberg. One of his teachers there, Fritz Wüst, who later became a professor at the Technische Hochschule at Aachen, recognizing Koppers' unusual abilities, predicted for him a great future.

In 1894 Heinrich Koppers joined the firm of Dr. C. Otto and Co. in Dahlhausen, and in 1899 while superintendent of the Mathias Stinnes mine he built his first battery of ovens for Hugo Stinnes, the German industrialist. Two years later he started his own organization, and in 1902 he made Essen his headquarters. It was to Essen that a group of engineers from the United States Steel Corp. went in 1906 with an invitation to Koppers to design and supervise the construction of four batteries of ovens at the Joliet works of the Illinois Steel Co. Each battery was to consist of 70 ovens. Arriving in the United States in 1907, Koppers established a branch of his firm in Joliet, and construction began. The first battery was fired on July 27, 1908. Rugged and simple, these ovens incorporated basic design features which were to make the Koppers oven and its future modifications the choice of a very large segment of the by-product coking industry of America.

C. S. FINNEY and JOHN MITCHELL are with Eastern Gas and Fuel Associates, Boston, Mass.

The 280 ovens at Joliet were 35 ft long, 8¾ ft in height, and tapered from 21 to 17 in. The total daily capacity of the four batteries was 2240 tons of coke. The ovens were of the new *cross-regenerative* type; that is, instead of longitudinal regenerators serving an entire battery, as in the older Koppers ovens, cross regenerators for each separate oven were employed. Fuel gas was supplied from the side of the battery through ducts in the brickwork known as *gun flues*, which reached to the center of the battery under the vertical heating-flues. Removable, ceramic gas-nozzles fitted at the top of each gun flue helped to insure good control over the distribution of the fuel gas, and uniform heating conditions were also promoted by regulating the air supply to, and the suction in, each heating flue. A different refractory was used for each battery. One was built of American silica brick, one of American quartzite, and two of imported German quartzite.

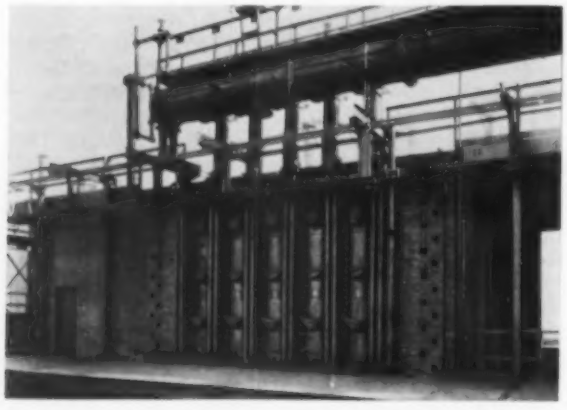
The installation at Joliet proved to be very successful, and in 1911, 490 additional Koppers ovens were built for the Illinois Steel Co. at the great new steelworks at Gary, Ind. By 1912 the H. Koppers Co. had established its headquarters in Chicago and was rapidly extending its business to include construction for such iron and steel companies as the Woodward Iron Co. at Woodward, Ala. (80 ovens in 1912); the Tennessee Coal, Iron and Railroad Co. at Fairfield, Ala. (280 ovens in 1912); the Inland Steel Co. at Indiana Harbor, Ind. (86 ovens during 1913 and 1914); and the Republic Iron and Steel Co. at Youngstown, Ohio (68 ovens in 1913).

In 1914 a group of men in Pittsburgh bought a major shareholding in the H. Koppers Co., and moved the headquarters of the organization from Chicago to their own city. Under its new management the company was highly successful in obtaining a large share of the contracts for by-product installations built during World War I. In 1917 the remaining German interests in the company were

taken over by the Alien Property Custodian, and subsequently passed into American hands. The Koppers Co., Inc. as it became, was to develop into the largest designer and builder of by-product ovens in the United States.

The Koppers cross-regenerative oven was not without faults, and difficulties were experienced, for example, with the single, horizontal flue (or *bus* flue) through which combustion gases passed from the heating flues to the downflow flues. Because this common flue handled the entire volume of combustion products from the battery, it had to be quite large. With the construction of greater capacity ovens and an increasing use of such lean fuels as blast-furnace gas or producer gas, the gas volume became such that an adequately sized horizontal flue could no longer be built without dangerously weakening the structure and seriously affecting the coking process.

The problem of the horizontal flue was solved by designing an entirely new heating system by which gas was burned in all the flues of one wall at the same time. The combustion products then passed over the top of the oven by means of several crossover flues, down through vertical flues on the other side, and thence to the stack by way of the regenerators and waste gas flue. The new design, for which US Patent 1,374,546 was granted on April 12, 1921 to J. Becker as assignor to the Koppers Co., Inc., allowed ovens to be built of up to 50 pct greater capacity than had been possible with the original heating system. Joseph Becker was born in Essen, Germany, on October 1, 1887. As the son of a local policeman, there were all too few opportunities for him to pursue his education beyond the age of 14, and he therefore took a job as an office-boy in a law office. It seems that young Becker had little interest in the law, for less than a year later he took another and very different job at a colliery which operated a battery of by-product coke ovens. It was there that he gained an early familiarity with carbonizing and recovery plant, and there also that he attracted the attention of Heinrich Koppers who in 1906 offered him a position as a chemist in the Koppers laboratories at Essen. Capable and energetic, his first really big opportunity came in 1910 when he was sent to Joliet in the United States as chief chemist for the Koppers organization. Two years later, Becker was appointed as superintendent of all Koppers operations in the US, with headquarters in Chicago. As the company expanded so did Joseph Becker move up in the organization. In 1944 he became vice-president and general manager of the engineering and construction div. of the Koppers Co., Inc., and in 1950 he was made a member of the Board of Directors.

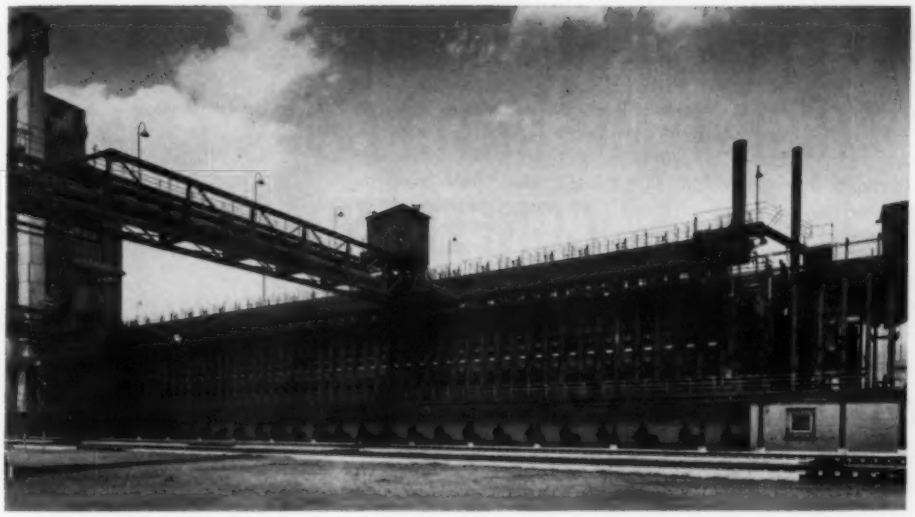


First Battery of Five Koppers-Becker Ovens Erected at the Chicago By-Product Coke Co. in 1922.

Although the horizontal flue was not eliminated in the Koppers-Becker oven, as it was named, it was possible to make it much smaller in cross-section than it had been in the Koppers cross-regenerative oven. In 1922, before making the new design generally available to industry, it was decided to build a small experimental battery of five Koppers-Becker ovens at a plant which the Koppers Co. operated for the Chicago By-Product Coke Co. of Chicago, Ill. The ovens were 37 ft long, 11 2/3 ft high, had a taper of 14¾ to 13¼ in. at the bottom and 13¾ to 12¼ in. at the top, and could be charged with 24 to 27 tons of coal. The battery was heated by producer gas. The success of this prototype installation brought rapid acceptance of the Koppers-Becker oven. In 1923 the Weirton Steel Co. put in 37 of the new ovens at Weirton, W. Va., and during the same year ovens were also under construction at Salt Lake City, Utah, at Alkali, Ohio, and at Warren, Ohio. A shorter version of the Koppers-Becker oven was also available to supply manufactured gas to small cities. Very similar in cross section, the short oven was about half the length of the full-size oven and accordingly was charged with approximately half the tonnage of coal.

An attempt to improve on the shortcomings of the old Koppers cross-regenerative oven was also made by Louis Wilputte, who at one time had worked for Heinrich Koppers in the United States. Wilputte was the son of a construction foreman from Flanders. As an employee of the firm of Evence Coppée, the elder Wilputte had been entrusted with the erection of the first Coppée ovens to be built in England—a battery of 30 ovens at Chapeltown near Sheffield. From Chapeltown he went to South Wales where the Coppée firm had a contract to build coke ovens at the well-known ironworks in Ebbw Vale. Remaining at the ironworks, Wilputte's father married a Welsh girl and became a naturalized British citizen. The son, Louis, was born in Ebbw Vale on December 21, 1876. At the age of 15, after finishing primary school, Louis Wilputte started work at the local ironworks, but four years later he went to Brussels where he obtained a job as a draftsman with Evence Coppée. In that capacity he had ample opportunity to learn the theoretical basis of coke oven construction. When 25 years old, Wilputte left Coppée for the firm of Dury and Piette, and his next three years were spent building coke ovens in the province of British Columbia. He happened to learn, however, of the possibility that Heinrich Koppers might build a large coke oven plant for the Illinois Steel Corp. and he therefore promptly left Canada for Essen where he persuaded Koppers to appoint him as his general manager in the US. Wilputte handled the negotiations with the United States Steel Corp. very capably, and quickly negotiated a contract for the erection of 280 ovens which were built under his direction during 1907-1908. Between 1913 and 1917 Wilputte cooperated with the various interests of Dr. C. Otto and Co. in America, but on July 1, 1917, he left the Otto Co. in order to work independently.

In July of 1917 Wilputte was granted US Patents 1,212,865 and 1,212,866 for an oven rather similar in design to the Koppers cross-regenerative oven. Separate regenerators were provided for each flue,



A Modern Installation of Koppers-Becker Coke Ovens.

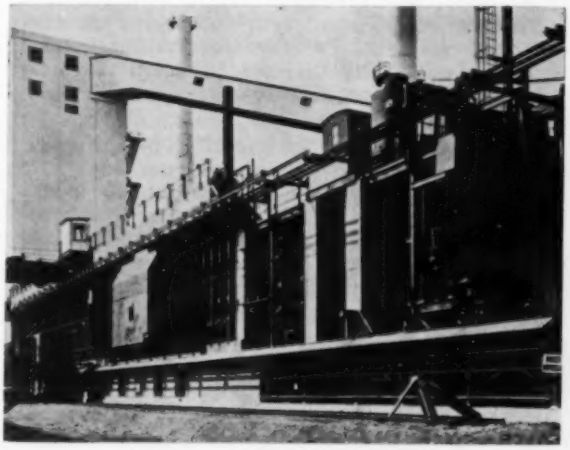
and a controlled quantity of air was supplied to each regenerator by means of forced draft from a blower. By a decision of the US Circuit Court of Appeals on May 22, 1919, however, it was held that the Wilputte oven was an infringement of US Patent 818,033 granted to Heinrich Koppers in 1906. Above the oven floor the Wilputte design did not greatly differ from that of the Koppers cross-regenerative oven, and it therefore did little to solve the problems associated with the horizontal flue. Subsequently, however, the size of the horizontal flue in Wilputte ovens was limited by dividing it at the center of the oven, giving, in effect, an oven consisting of two short, cross-regenerative ovens placed end to end. Since 1940, when Louis Wilputte disposed of his interests in the Wilputte Coke Oven Corp. to the Allied Chemical and Dye Corp., Wilputte ovens have been erected by the latter organization.

The development of the by-product coking industry during the twentieth century was steady rather than spectacular up until the outbreak of World War I. The stimulus of wartime demand for coke and by-products, however, led to a sharp increase in the rate of oven building, so that by 1918 more than twice as much coke (26 million tons) was being produced than had been made in 1914 (11.2 million tons). In 1919 the quantity of coke from by-product ovens exceeded that turned out by the beehive section of the industry, and in the years following, the slot oven supplied an increasing share of the country's production at the expense of the beehive oven. During the depression years of the early 1930's, by-product coking suffered along with all other sectors of business and industry. From a peak of 53.4 million tons of coke in 1929, production fell to 45.2 million tons in 1930, 32.4 million tons in 1931, and a low of 21.1 million tons in 1932. The industry gradually recovered during the later 1930's and then entered a period of remarkable activity during World War II; in 1944, for instance, more than 67 million tons of by-product coke were produced. Under the influence of an expanding economy the demand for coke reached new heights after the second World War, and in 1953 an all-time record output of 78,836,857 tons was attained, of which 73,593,528 tons came from by-product ovens. Production of by-product coke reached a maximum in 1957 when 73,860,692 tons were made out of a total of 75,950,721 tons.

(To be continued)

By-Product Coking During the 20th Century

Year	Ovens in Existence at End of Year	Ovens Built	Tons of Coke Produced
1900	1,081	65	1,075,727
1905	3,135	213	3,462,348
1910	4,082	89	7,138,734
1914	5,660	228	11,219,943
1915	6,238	670	14,072,895
1916	7,240	1,002	19,069,361
1917	7,819	579	22,439,280
1918	9,229	1,800	25,997,580
1920	10,771	1,044	30,833,951
1925	11,278	404	39,912,159
1930	12,771	533	45,195,705
1931	12,864	93	32,355,549
1932	12,809	87	21,136,842
1933	12,809	—	26,678,136
1934	12,857	138	30,792,811
1935	12,754	177	34,224,053
1940	12,623	3	54,014,309
1941	12,910	687	58,482,422
1942	13,303	423	62,294,909
1943	14,253	1,010	63,742,676
1944	14,580	568	67,064,795
1945	14,510	176	62,694,288
1950	14,982	552	66,890,618
1955	15,980	641	73,584,214
1956	15,923	361	71,992,242
1957	15,897	560	73,860,692
1958	16,244	808	53,005,730
1959	15,993	101	54,612,986



A Modern Battery of Wilputte Ovens.

A Review of the HIGH-TEMPERATURE MATERIALS CONFERENCE

A summary of the AIME Technical Conference on High-Temperature Materials, Cleveland, Ohio, April 26-27,1961.

Materials for use at temperatures above 1600°F in aircraft, missiles, and nuclear reactors were the subject of 42 technical papers and two panel discussions presented at a technical conference on *High Temperature Materials,* held at the Pick-Carter Hotel in Cleveland, Ohio, April 26-27. The two-day meeting, the largest technical conference sponsored by a local section of AIME, attracted more than 662 scientists and engineers from this country and abroad. The conference was organized by the Cleveland section of AIME in cooperation with the Refractory Metals and the High Temperature Alloys Committees of The Metallurgical Society's Institute of Metals Division.

General chairman, H. P. Munger, addressed several remarks to the large audience, and then introduced A. D. Schwope, chairman of the Cleveland section of AIME, who welcomed the registrants to the city on Lake Erie and to the conference.

Getting the conference off to a lively start, a panel discussion on *Requirements for High Temperature Materials,* moderated by N. E. Promisel, Bureau of Naval Weapons, elucidated on material requirements up to 8000°F. Included on the panel of experts were: G. Wile, General Electric Co., who discussed material requirements for *Air Breathing Devices* (pertaining to aircraft and ram jets as opposed to rockets and other space craft); R. A. Perkins, Lockheed Aircraft Corp., who covered *Chemical Rockets,* including material requirements for both solid and liquid fuel rockets; G. M. Ault, Lewis Research Center, NASA, who described the four basic types of rockets, and explained some of the difficulties encountered in rockets requiring large power sources under the general heading of *Space Vehicles;* W. H. Dukes, Bell Aerosystems Inc., who discussed the material requirement problems associated with *Hypersonic Re-entry Vehicles;* and the final panelist, A. E. Focke, ANPD, General Electric Co., who discussed material requirements for high-temperature *Nuclear Applications.*

At the conclusion of the formal panel program, the panelists agreed to answer any questions, and thus initiated a lively discussion with audience participation.

In the afternoon, two simultaneous sessions, one on *Tungsten, Tantalum and Their Alloys,* and the other on *Cobalt and Nickel Base Alloys,* provided the technical program. In the tungsten session the introductory paper, *Status and Future of Tantalum, Tungsten, and Their Alloys,* by H. R. Odgen and D. J. Maykuth of Battelle Memorial Institute, was a review paper. The procedure of presenting a state-of-the-art paper at the beginning of each session was followed in most of the sessions of the conference.

Mechanical Properties of Arc-Melted Tungsten and Some Tungsten Alloys by F. A. Foyle, Lewis Research Center, NASA, reported on high-temperature tensile and extrusion tests on vacuum-melted tungsten-molybdenum, tungsten-tantalum, and tungsten-columbium alloys.

J. R. Stephens, also from Lewis Research Center, described an investigation to evaluate quantitatively the role of surface condition on the ductile-to-brittle transition temperature in a paper entitled, *Effect of Surface Condition on the Ductility of Tungsten.* Tensile and bend test specimens of commercially-pure sintered tungsten were tested at various temperatures to determine the ductile-to-brittle transition temperature, and it was found that the removal of approximately 0.005 in. from the specimen surface by electropolishing yielded the lowest transition temperatures. However, there was much debate from the audience as to whether the surface condition or the subsequent removal of surface impurities was the cause of the improved properties.

Other papers in this session dealt with the properties, fabrication, and high-temperature oxidation behavior of tantalum-base alloys.

Status and Future of Cobalt and Nickel Base Alloys, presented by W. H. Sharp, Pratt & Whitney Aircraft, inaugurated the cobalt and nickel session. *Nickel Base Alloys for the 1960's* by C. S. Freer, R. A. Woodall, and S. Abkowitz, Kelsey-Hayes Co., was concerned with the development of three nickel-base alloys aimed at meeting the stringent requirements of the current decade, particularly at improving forgeability, while retaining creep-rupture properties at increased temperatures.

A New Series of High Temperature Nickel-Base Alloys by J. C. Freche, W. J. Walters, and T. J. Riley, Lewis Research Center, NASA, described a recently-developed series of nickel-base alloys with good strength and impact characteristics up to 1900°F, which require no vacuum melting. The alloys are obtained by modifying the following base alloy: 8 pct Mo, 6 pct Cr, 6 pct Al, 1 pct Zr, bal Ni with W, Ti, V, and C. On the basis of the investigation, it appears that the alloys have a considerable potential for elevated-temperature applications, particularly in turbine blades. *Effect of Alloying on the Properties of Wrought Cobalt* by J. J. Rausch, J. B. McAndrew, and C. R. Simcoe, Armour Research Foundation, was a report on the results of research directed toward determining the effect of a wide variety of alloying elements on the properties of cobalt. Alloying influence on forgeability, elevated temperature strength, ductility, and oxidation resistance was presented for binary, ternary, and more complex cobalt-base alloys.

Some of the men responsible for the success of the conference: from left to right, W. A. Johnson, D. C. Johnston, K. L. Fetters, G. M. Low, H. P. Munger, A. D. Schwope, and G. M. Ault.

Other papers presented at this session were concerned with the effect of heat treatment on a cast, age-hardenable, nickel-chrome alloy, effect of phase changes on the workability and properties of Udimet 700, and the effect of metallurgical factors on creep-rupture at very high temperatures.

The Fellowship Hour preceding the Dinner on Wednesday evening presented an opportunity for the registrants at the conference to renew old acquaintances and make new ones in an informal atmosphere. George M. Low, chief, Manned Space Flight, NASA Headquarters, presented an extremely interesting and timely after-dinner talk, *Manned Flight in Space*. Mr. Low discussed *Project Mercury*, the first step in the US's manned flight space program, which is to orbit a man around the earth three times and bring him back safely, and *Project Apollo* which is the long range program to put a man on the moon. In *Project Apollo*, the first phase will be the launching of a three-man space laboratory to orbit the earth in order to gather data for the future moon flight. Launching date is scheduled to be about 1966. If the orbital laboratory is successful, the next step in the project will be a manned flight around the moon, expected to take place about 1967-68; it would take approximately two to three days to complete. The purpose of circumnavigating the moon would be to provide accurate data concerning re-entry problems on returning from a lunar expedition. Depending on the success of the previous steps a lunar landing might be attempted, in 1971.

In addition to the excellent talk, dinner guests were treated to a film of the April 25th Atlas launching which was a preparatory step for the May 5th launching of Commander Alan Shephard, the US's first astronaut. After the film, a very excited and interested audience asked numerous questions of the speaker until time eventually ran out.

On the second day of the conference, *A Panel on the Processing and Fabrication of Refractory Metals*, moderated by W. A. Johnson, Thompson Ramo Wooldridge Inc., constituted one of the simultaneous sessions. *Powder Metallurgy* techniques were described by R. C. Nelson, Sylvania Electric Products, Inc.; *Melting* techniques were described by W. Ashoff, Wah Chang Corp.; and *Casting* techniques were described by R. A. Beall, Federal Bureau of Mines, Albany Metallurgy Research Center.

Concerning the working of refractory metals, Capt. P. Duletsky, ARDC, US Air Force described *Extrusion* techniques; *Forging* techniques were discussed by A. S. Nemy, Thompson Ramo Wooldridge Inc.; and *Rolling to Sheet* was described by P. C. Rossin, Universal-Cyclops Steel Corp. *Joining* techniques were described by H. Schwartzbant, Armour Research Foundation.

At the other simultaneous session, L. P. Jahnke, General Electric Co., presented the review paper, *Status and Future of Molybdenum, Columbium and Their Alloys*. Other papers presented during the session covered the following subjects: mechanical properties of columbium-base alloys, aging phenomena in columbium-base alloys, columbium alloys for nuclear applications, and solutions and aging reactions in molybdenum-base alloys.

On Thursday afternoon, registrants had the choice of attending any of three simultaneous sessions, *Fabrication of Refractory Metals, Graphite and Refractory Compounds,* and *Coatings on Refractory Metals.*

The fabrication session concerned itself with extrusion studies, effects of melting variables on purity and properties, and welding of refractory metals.

A relatively new fabrication process was also described at this session in the paper, *Fabrication of Tungsten Shapes by Plasma Arc Spray Techniques*, by R. H. Singleton, E. L. Bolin, and F W. Carl, General Motors Corp. (see p. 483 of this issue of JOURNAL OF METALS).

A paper on *High Energy Rate Extrusion of Columbium-Base Alloys* by R. T. Begley and R. L. Ammon, Westinghouse Electric Corp., described the *Dynapak* extrusion of a series of high-strength columbium alloys, and compared this process to conventional extrusion methods.

During the graphite and refractory compound session, R. T. Doloff and J. T. Meers, National Carbon Co., presented the *Status and Future of Graphite and Refractory Compounds*. Other papers during the session discussed the high-temperature tensile properties and deformation mechanisms of pyrolytic graphite, high-temperature properties of titanium diboride, refractory beryllium compounds, and fabrication and properties of hafnium carbide.

In the coatings session, a review paper, *Status and Future of High Temperature Coatings for Refractory Metals* was presented by J. J. Gangler, Lewis Research Center, NASA. This review paper pointed out that there is a lack of fundamental knowledge regarding oxidation protection of the refractory metals because of insufficient basic research on this problem. Papers presented at this session were concerned with metallic and non-metallic coatings for molybdenum, columbium, tantalum, and their alloys.

As the technical sessions came to an end there were the *Goodbyes till next time, handshakes, trains and planes to catch*, and the usual mass exodus from the hotel. Thus ended a very interesting and successful conference.

General chairmen H. P. Munger and G. M. Ault deserve a huge vote of thanks for a job well-done. The Cleveland section, and especially its Chairman, A. D. Schwope, deserve resounding applause for providing an outstanding technical program and doing an outstanding job on the mechanics of running the conference. Here's looking forward to additional conferences of this calibre in Cleveland in the near future.

EJF

Phases and Processes

HIGHLIGHTING CURRENT DEVELOPMENTS IN METALS

Rare Earth Horizons

by L. D. Lash of Vitro Chemical Co.

A surge of research on rare earth metals, alloys, and compounds promises to open new horizons in this field. The individual rare earths, along with yttrium and scandium, are subjects of intense investigation by two approaches: systematic determination of physical and chemical properties, and a quest for special properties to solve specific problems. The latter leads to tailor-made alloys, electronic components, and nuclear-control devices. Industrial, academic, and government institutions are active in this development program.

Paradoxically, the rare earths are generally in oversupply rather than being rare. Excess plant capacity has forced producers to seek expanded markets. At the same time, the rare earths have many unique and useful properties which will find wide application, if prices are reduced to compete with alternative materials. Volume production and improved techniques will result in pure rare earths at significantly lower prices.

Due to the lanthanide contraction, the chemical properties of many rare earths are similar, making separation difficult. However, ion exchange techniques, using complexes for greater fractionation, have supplied relatively pure rare earths in abundance. Also, methods based on oxidation or reduction of the normal three-valent state enable cerium, samarium, and europium to be *picked out* from the other elements.

Advance research achievements in the rare earth field were explored at a Lake Arrowhead Seminar entitled *Rare Earth Research Developments*.[1] The meeting, which was sponsored by University of California, U.S. Air Force, Office of Scientific Research, U.S. Navy Office of Naval Research, and Research Chemicals div. of Nuclear Corp. of America, was especially oriented to users of rare earths and researchers who would potentially use them. The symposium included solution chemistry, oxide systems, and metals and intermetallic compounds. The uses of rare earths for semiconductors and thermoelectric converters were described. A collection of these papers will be published in the near future by MacMillan and Co. A *Second Rare Earth Conference* will be held in September 1961 at Glenwood Springs, Colo.

Metals and Intermetallics

The preparation of pure rare earth metals has received impetus in both research and production areas. Typical in this field are Iowa State University at Ames where the pioneering work on rare earth separation and reduction was done,[2] the U.S. Bureau of Mines at Reno where large-scale fused salt electrowinning is being explored,[3,4] and Michigan Chemical Corp., which, among others, commercially prepares rare-earth metals.

In the field of alloys, addition of yttrium or rare earths to steel,[5] particularly the chrome type, improves the grain structure, imparts higher-temperature oxidation resistance and acts as a gettering agent in removing impurities. Cost is a big factor in this application, and development of less expensive yttrium metal or an inexpensive ferroalloy of yttrium would accelerate its use.

Alloys of magnesium containing rare earths exhibit improved physical properties at high temperatures.[6] Didymium master alloys, consisting of mixed praseodymium and neodymium in magnesium, are added to magnesium castings as a hardener.

Lanthanum has recently been shown to improve the grain-refining of beryllium metal. This could be of major import, if it would reduce the brittleness of beryllium.

A low melting plutonium-cerium-cobalt alloy is being considered for fuel elements on the LAMPRE reactor (Los Alamos Molten Plutonium Reactor Experiment).

The rare earths will react with other metals to form intermetallic compounds, many of which exhibit superconductivity or ferromagnetism.[1] In Group IIIa only lanthanum is superconducting in elemental form, but many noble metal compounds of lanthanum, yttrium, and scandium with ruthenium, osmium, iridium, and also germanium are superconductors.

Ferromagnetism is exhibited by the heavy rare earths which have a hexagonal close-packed crystal structure, but all rare earths form ferromagnetic compounds with ruthenium, osmium, or iridium. Apparently the formation of a compound or alloy eliminates the differences in crystal structure among the individual rare earths.

New intermetallic compounds between rare earth or yttrium metals and iron, cobalt, nickel, and manganese, with the general formula AB_2 or AB_5 were recently prepared and studied. Cobalt, for example, forms both ACo_5 and ACo_2 compounds with yttrium and nearly all the rare earths. The magnetic properties of these compounds reveal both ferri- and ferromagnetism.

Rare earth intermetallic compounds with Groups V and VI have also been prepared.

Artificial Garnets

Yttrium iron garnets (YIG) with low eddy losses and low electrical resistance at high frequencies are finding application as components for microwave and television.[8] The higher cost of these ferrites is justified by the narrow absorption band characteristics. Garnets with interesting properties have also been made from lutetium (LuIG) and scandium (ScIG). Very high purity is required in ferrites.

The thermal and magnetic properties of rare earth oxides and perovskites are providing valuable tools for the determination of solid-state phenomena and structures.[1] Computers are being used to expand

fundamental theories so that they will explain and correlate the solid-state data for rare earths.

Nuclear Uses

Several rare earths are under consideration as reactor control materials because of their relatively high neutron cross-sections. Also, their oxides may provide high-temperature nuclear poisons. Europium makes an excellent long-lived control material, because capture of neutrons merely produces a heavier isotope of the same element. Europium-151, for example, will pass through five europium isotopes before transmuting to a low cross-section substance.[9] The recent discovery that dysprosium oxide and europium oxide may be stabilized against corrosion by high-temperature water with titania promises their wider use.[10] Hydrogen firing of europium oxide at 1700°C also stabilizes europium oxide against hydration.

Gadolinium and samarium may be used as a burnable poison in control rods or fuel elements, since neutron bombardment transmutes them into elements with low cross-sections. As the nuclear fuel is consumed, an ideal burnable poison would be consumed at a rate which maintains the reactor at a constant level of activity.

Rare earths are also under consideration for scram or emergency shutdown poisons.

Yttrium metal is extremely resistant to corrosion by liquid metals, such as sodium, which could offer a potential for yttrium in the liquid-metal-cooled reactor concepts. Yttrium, which has a low cross-section, is completely immiscible with uranium in all proportions.[11] A series of dispersions, based on the Y-U system, are expected to offer advantages on radiation stability and reprocessing cost. Yttrium hydride exhibits exceptional high temperature properties[12] and may prove valuable in neutron moderator use.

Semiconductors and Thermoelectric Converters

The rare earths will form a complete new series of semiconductors with the Group VI elements selenium, tellurium, and sulfur.[3] These compounds are being prepared and studied at Battelle Memorial Institute, where they find a gradation of electrical properties through the semiconductor area. This could provide a wide range of semiconductors with almost any desired resistivity for the electronic industry.

Semiconducting compounds of rare earths with sulfur and selenium—because of their high electron mobilities—show promise as thermoelectric converters which will change heat directly to electricity.[1] These materials are chemically stable and have low thermal conductivity at high temperatures (800° to 1600°K) when compared with other semiconductors such as germanium, silicon, and lead telluride. The compounds of cerium sulfide, samarium sulfide, and gadolinium selenide show particular promise for this application.

Volume Production

Cerium oxide is an excellent polishing agent for glass[13] and is beginning to be used to polish plastics and metals. Mixed rare earths, available at lower cost, are also being used for polishing, although grinding efficiency is lower. Optical lenses, plate glass, television tubes, and mirrors are polished with cerium and mixed rare-earths oxides. Pure lanthanum oxide is used for optical lenses with a high index of refraction but low light dispersion. Cerium is used for radiation windows and decolorizing glass, while neodymium and praseodymium will color glass red, yellow, or green.

Rare earth fluorides are used in quantity for carbon arc-electrodes because they emit a high-intensity spectrum similar to natural sun light.

Misch metal, a mixture of rare earth metals, is used in lighter flints because of its pyrophoric nature.

While the separated rare earths will diminish markedly in price as production increases, the lower-priced volume-produced products described above will drop only slightly in the future.

Purple europium oxide is prepared in this temperature - controlled induction furnace at the Chattanooga plant of Vitro Chemical Co.

References

[1] E. V. Kleber: Rare Earth Research Developments, tentative title, *The Macmillan Co.*, New York, Spring 1961.

[2] J. E. Powell and F. H. Spedding: Basic Principles Involved in the Macro Separation of Adjacent Rare Earths from Each Other by Ion Exchange, *CEP* Sym. series 55, 1959, pp. 101-113.

[3] Mineral Facts and Problems, *USBM* 1960 edition, chapters on Rare-Earth Metals, Yttrium and Scandium.

[4] B. Porter, E. S. Shedd, C. Syche, J. D. Marchant, and R. G. Knickerbocker: Higher Purity Ingot Cerium from Molten Salts, JOURNAL OF METALS, vol. 12, no. 10, Oct. 1960, pp. 798-801.

[5] J. F. Collins, V. P. Calkins, and J. A. McGurty: Application of Rare Earths to Ferrous and Non-Ferrous Alloys, *AECU-4424*, Nov. 1959.

[6] J. V. Winkler: Progress in Magnesium Alloys, *Metal Progress*, Oct. 1960, p. 146.

[7] D. H. Gurinsky: Molten Metal Fuels, *ASM* Sym. on Recent Develop. in Mat. for Nuclear Applications, Albuquerque, N. M.

[8] R. C. Vickery: The Chemistry of Yttrium and Scandium, *Pergamon Press*, New York, 1960.

[9] Survey of the Physics, Metallurgy, and Engineering Aspects of Reactor Control Materials, General Electric Co., *GRAP-3183*, June 1959.

[10] T. J. Pashos: A Review of Recent Develop. in Reactor Control Materials, presented *ASM* Sym. Recent Develop. in Mat. for Nuclear Applications, Albuquerque, N. M.

[11] I. Sheinhartz and J. L. Zambrow: Yttrium—Uranium Alloys for High Temperature Fuel Elements, *ANS* Trans., vol. 3, no. 2, Dec. 1960, pp. 22-23.

[12] E. S. Funston: Properties of Yttrium Hydride, JOURNAL OF METALS, vol. 12, no. 9, Sept. 1960, p. 738 (abstract).

[13] L. K. Duncan: Cerium Oxide for Glass Polishing, *Glass Industry*, vol. 41, no. 7, July 1960.

AIME STAFF:

SECRETARY—ERNEST KIRKENDALL

ASST. SECRETARIES—J. B. ALFORD, H. H. APPLETON, J. C. FOX, R. W. SHEARMAN, C. J. HICKS

ASST. TREASURER—JOHN LYNCH

METALLURGICAL SOCIETY STAFF:

SECRETARY—R. W. SHEARMAN

ASST. SECRETARY—O. C. JOHNSTON

NEWS OF YOUR PROFESSION

Richard C. Cole Nominated as 1962 President-Elect of The Metallurgical Society

Richard C. Cole

Richard C. Cole has been nominated for Vice President and President-Elect of The Metallurgical Society according to an announcement by A. E. Lee, Jr., Chairman of The Metallurgical Society's Nominating Committee. Mr. Cole will serve a one-year term, beginning in February 1962. He automatically becomes President of the Society in 1963.

Mr. Cole recently became executive vice president and general manager of White Pine Copper Co., a subsidiary of Copper Range Co. He was formerly vice president of both Vitro Chemical Co., and Vitro Minerals Corp., having joined Vitro in 1954.

Graduated from the University of Washington in 1941 with a B.Sc. in metallurgical engineering, Mr. Cole joined AIME as a student and served as president of the university's student chapter. He was active in various section committees and was General Chairman of the Rocky Mountain Minerals Conference. He is also a Past Chairman of the Utah section. Mr. Cole is a Director of AIME and the Chairman of the Extractive Metallurgy Division.

Nominating Committee

Each of The Metallurgical Society's three divisions, IMD, EMD, and ISD, nominated three members for The Metallurgical Society Nominating Committee.

Those nominated by the Institute of Metals Division are J. H. Jackson, Battelle Memorial Institute; Morris Cohen, Massachusetts Institute of Technology; and D. J. Blickwede, Bethlehem Steel Co.

The Extractive Metallurgy Division nominees are: B. W. Gonser, Battelle Memorial Institute; H. H. Kellogg, Columbia University; and A. E. Lee, Jr., Americal Metal Climax, Inc.

The Iron and Steel Division has nominated P. R. Gouwens, Armour Research Foundation, and T. F. Olt, Armco Steel Corp.

Board of Directors

The Nominating Committees of each division (IMD, EMD, and ISD) have nominated one member of their respective division for the Board of Directors of The Metallurgical Society. The nominees are: C. S. Barrett, University of Chicago IMD; R. Schuhmann, Jr., Purdue University, EMD; and A. B. Wilder, National Tube div., U. S. Steel Corp. They will serve for three years.

For AIME nominations, turn the page.

USE the SERVICES of THE ENGINEERING SOCIETIES LIBRARY

29 West 39 Street,
New York 16, N. Y.

Metallurgical Society Division Officers Nominated for 1962

Nominees for division officers and Executive Committee members to serve in 1962 have been submitted by the Nominating Committees of the Iron and Steel Division, Extractive Metallurgy Division, and Institute of Metals Division. The chairman of each division will serve one year on the Board of Directors of The Metallurgical Society coincident with his chairmanship.

IMD

The Institute of Metals Division nominees are: Chairman, David Swan, Union Carbide Metals Co.; Senior Vice Chairman, R. L. Smith, Michigan College of Mining & Technology; Vice Chairman, James Keeler, General Electric Co.; Secretary-Treasurer, D. C. Johnston. Serving on the Executive Committee for three-year terms (through 1965) will be: Frederick Seitz, Univ. of Illinois; Morris Fine, Northwestern Univ.; and Leslie L. Seigle, General Telephone & Electronics Laboratories, Inc.

EMD

The Extractive Metallurgy Division nominees are: Chairman, W. R. Opie, National Lead Co.; Chairman-Elect, C. L. McCabe, Carnegie Institute of Technology; Secretary, R. W. Shearman; Treasurer, A. E. Lee, Jr., American Metal Climax, Inc.; Executive Committee Members (1962-65): R. L. Hennebach, American Smelting & Refining Co.; and W. D. Wilkinson, Argonne National Laboratory.

ISD

The Iron and Steel Division has nominated: Chairman, B. M. Larsen, U. S. Steel Corp.; Chairman-Elect, D. R. Loughrey, Jones & Laughlin Steel Corp.; Secretary-Treasurer, R. W. Shearman; Executive Committee Members, (through 1965), R. E. Powers, Koppers Co., Inc., and R. G. Phelps, Inland Steel Co.

Arthur B. Lytle

Arthur B. Lytle Named New Treasurer of Metallurgical Society

Arthur B. Lytle, senior consultant, in the Electric Welding Dept., Linde Co., has been nominated as Treasurer of The Metallurgical Society of AIME. He will succeed T. D. Jones in February 1962.

Mr. Lytle, a graduate of Rensselaer Polytechnic Institute, worked for more than 25 years in the Metals Research Laboratories of Union Carbide Metals Co. on problems directly concerned with welding.

As a result of Mr. Lytle's technical activities, 25 patents on materials and processes were issued in his name.

Mr. Lytle is a member of the Education Committee, the Finance Committee, and the Fiscal Policy and Future Developments Committee. He is also Chairman of the Metals Research Publications Fund Committee.

Nominees Announced For Education Council's Executive Committee

The Nominating Committee of the Council of Education of AIME has announced its nominees for the Council's Executive Committee. They will take office in February 1962. The current Vice Chairman, A. W. Schlechten, automatically becomes Chairman. Others nominated are: Vice Chairman (for one year) Truman Kuhn; Secretary-Treasurer (for one year), Robert L. Whiting. Nominated as Executive Committee Member-at-large for three years is Charles F. Weinaug. The current Chairman, Charles V. Kirkpatrick, automatically becomes Past Chairman and a member of the Executive Committee.

Magnetism Conference Set For November 13-16 In Phoenix, Ariz.

Representatives from USSR, Japan, UK, and France will speak at the Seventh Annual International Conference on Magnetism and Magnetic Materials which will be held November 13-16 at the Westward Ho Hotel in Phoenix, Ariz., Peter B. Myers, local chairman for the conference, said that more than 1000 scientists and engineers are expected to attend the meeting. Dr. Myers is staff scientist for the Semiconductor Products div., of Motorola, Inc.

The conference is being sponsored jointly by the American Institute of Electrical Engineers and the American Institute of Physics, in cooperation with The Metallurgical Society, the Office of Naval Research, and the Institute of Radio Engineers.

Papers on basic theoretical and experimental investigations, potential engineering applications, and apparatus and techniques which utilize recent advances in magnetism are being solicited.

Authors should submit abstracts by August 18 to *Dr. F. E. Luborsky, General Electric Co., Research Laboratory, P.O. Box 1088, Schenectady, N. Y.*

Call for Papers

July 15 is the deadline for the receipt of abstracts of papers to be considered for presentation at the symposium on the *Theory of Work Hardening* which will be presented Monday, October 23 during the 1961 Fall Meeting in Detroit. The symposium will be sponsored by the IMD Chemistry and Physics of Metals Committee.

In addition to a session of invited talks, time will be available for presentation of a limited number of research papers on work hardening. Prospective contributors are invited to forward abstracts (two copies) and information sheets giving the name and address of all authors *no later than* July 15, to the Symposium Chairman;

Prof. G. M. Pound
Dept. of Met. Engr.
Carnegie Inst. of Tech.
Pittsburgh, Pa.

R. V. Pierce Nominated President-Elect of AIME For 1962

Roger V. Pierce has been nominated by the Society of Mining Engineers as AIME President-Elect for 1962. He will become President of AIME in 1963.

Mr. Pierce is a consulting engineer in Salt Lake City, Utah. He graduated from the Montana School of Mines, and from 1937-47 was employed by Ingersoll-Rand Co., as a specialist in underground mining methods. From 1947-50, Mr. Pierce was vice president of Cate Equipment Co., in Salt Lake City, and during this period established his mining consulting business.

Roger V. Pierce

He has served on numerous AIME committees including the Jackling, Saunders, and Peal Award Committees. He is currently Chairman of the Saunders Award Committee. Mr. Pierce is Past Chairman of the Utah section of AIME and a past member of the Council of Section Delegates. He has also served as a Vice President of AIME.

French Metals Society Will Meet Oct. 16-20

The Autumn Meeting of the Société de Française de Métallurgie will be held October 16-20, 1961 at the Maison de la Chemie in Paris.

The Forming of Metals will be the main topic of the meeting, which will cover hot and cold deformation and also casting and sintering. Papers on other subjects will also be presented.

Further information may be obtained from the Société Française de Métallurgie, 25 Rue de Clichy, Paris 9, France.

Nominations Announced for 1962 AIME Officers

The Chairmen of the three Society Nominating Committees have announced nominations for AIME President-Elect, Vice Presidents, and Directors for 1962.

Each of the Society's Bylaws provides for additional nominations. (The Bylaws of each Society in substantially final form have been published in the Journals and in revised form in the 1957 Institute Directory). If no alternate slate is proposed, no letter ballot will be necessary and the selections of the three Nominating Committees will be declared elected, in accordance with the respective Society Bylaws, well in advance of their installation at the 1962 Annual Meeting in February in New York.

Vice Presidents

C. C. Long

Carleton C. Long, director of research, zinc smeling div., St. Joseph Lead Co., has been nominated to serve a one-year term as Vice President of AIME. He will complete a similar term in 1962. He has been appointed to the Board of Directors to fill the remaining two years of the unexpired term of Richard C. Cole. Dr. Long was the 1960 President of The Metallurgical Society.

Dr. Long joined AIME in 1937, and has been very active in the affairs of the Institute. He was Chairman of the Lead-Zinc Committee in 1948 . . . one of the founders of the Extractive Metallurgy Division, and its Chairman in 1950 . . . Chairman of the Metals Branch Council in 1951, . . . and Chairman of the Douglas Award Committee in 1956. Dr. Long has also served two terms (1954-57 and 1959-62) as an AIME Director.

After receiving his doctorate from the University of Colorado in 1935, Dr. Long joined St. Joseph Lead Co. as a research engineer with the Josephtown smelter of the zinc smelting div., Monaca, Pa. He became director of the plant research department at Josephtown in 1937, a post he held until assuming his present position.

J. S. Smart, Jr.

J. S. Smart, Jr. has been nominated to represent The Metallurgical Society as a Vice President of AIME. He is currently President of The Metallurgical Society and a member of the AIME Board of Directors.

Mr. Smart is general sales manager of American Smelting & Refining Co. He joined the company as a research metallurgist in 1936, and assumed his present position in 1958. A graduate of the University of Michigan, Mr. Smart gained his early experience with the Ford Motor Co. and Detroit Lubricator Co.

Active in AIME for many years, Mr. Smart was Chairman of the AIME Rossiter W. Raymond Award Committee in 1954, and received the Institute of Metals Division Award (now the Mathewson Gold Medal Award) in 1948. His current term as Vice President of AIME expires in February 1962.

J. C. Gray

James C. Gray, 1961 President of the Society of Mining Engineers, has been nominated for a one-year term as Vice President of AIME beginning in February 1962.

Mr. Gray is administrative vice president, of raw materials, U.S. Steel Corp. He has been with the company for 24 years.

A native of Pennsylvania, Mr. Gray is a graduate of Pennsylvania State University. Upon graduation, he worked with the Hudson Coal Co. for 12 years. He joined the Tennessee Coal & Iron div. of U.S. Steel in 1937 as superintendent of the Wylam mine at Fairfield, Ala. He became vice president of the coal div. in 1954.

W. B. Stephenson

W. B. Stephenson, President-Elect of SME, has also been nominated to serve a one-year term as Vice President of AIME.

Since 1956, Mr. Stephenson has been president of Allen-Sherman-Hoff Pump Co. (design and application of sand pumps to mining and metal industry), Frazer, Pa. He is a graduate of Pennsylvania State University.

Mr. Stephenson is Past-Chairman of the Minerals Benefication Division of SME and served as General Chairman for the AIME International Symposium on Agglomeration which was held in Philadelphia in April 1961.

Earl M. Kipp, the 1961 President of the Society of Petroleum Engineers has been nominated by that group for a one-year term as Vice

E. M. Kipp

President of AIME beginning in 1962.

Mr. Kipp, a graduate of Stanford University, is special consultant—handling problems of production—on the staff of the vice president in charge of producing for Standard Oil Co. of California.

An active member of SPE for many years, Mr. Kipp has served as a Vice President in 1957, a member of the Executive Committee (now Board of Directors) in 1955-56, and Chairman of the Technology Committee in 1951.

H. F. Beardmore

Herbert F. Beardmore is the Society of Petroleum Engineers' second nominee for a one-year term as Vice President of AIME to begin in 1962.

Mr. Beardmore is vice president of Gulf Oil Corp. in Houston, Tex.

He attended the University of Oklahoma and was the first petroleum engineering graduate from that school in 1925.

Mr. Beardmore was 1941 Chairman of the Mid-Continent section, member of the Petroleum Division General Committee in 1944, and Petroleum Division Chairman in 1946.

Directors

H. B. Emerick

Harold B. Emerick has been nominated for a three-year term as a Director of AIME. Mr. Emerick is director of technical services for Jones & Laughlin Steel Corp., having joined the company in 1935. He attended Carnegie Institute of Technology.

Mr. Emerick is a Director of The Metallurgical Society representing the Iron and Steel Division, of which he was Chairman in 1957-58. In 1942 he was co-author of the paper on open-hearth practice which won the *F. B. McKune Memorial Award.* Mr. Emerick is also co-editor of *Basic Open Hearth Steelmaking,* which was published by AIME in 1951. In addition to AIME, Mr. Emerick is a member of the American Society for Metals and the American Iron and Steel Institute.

Carleton C. Long is The Metallurgical Society's second nominee for the AIME Board of Directors. His biography appears on the preceding page.

N. L. Weiss

Norman L. Weiss will begin a three-year term as an AIME Director from the Society of Mining Engineers in February.

Mr. Weiss, who attended Massachusetts Institute of Technology and Pennsylvania State University, is employed by American Smelting & Refining Co., where he is concerned with the metallurgy of ore beneficiation and milling plant design. He joined the company in 1924. From 1926 to 1945 he was concerned with the company's Mexican operations. For 18 months in 1946-47, Mr. Weiss worked for Dow Chemical Co. as field metallurgical engineer. He rejoined American Smelting & Refining in 1947.

Edward G. Fox has been nominated for a three-year term as a Director of AIME representing the Society of Mining Engineers. He is Eastern Regional Vice President of SME, serving a three-year term ending in 1964.

Since 1956, Mr. Fox has been president of the Bituminous Coal Operators Assn., which carries on labor relations with the United Mine Workers of America. A graduate of Pennsylvania State University, he was president of Philadelphia & Reading Corp. before taking his present position.

E. G. Fox

R. A. Morse, who has been nominated as the 1962 President of the Society of Petroleum Engineers, has also been nominated by that group for a three-year term, beginning in 1962, as a Director of AIME.

Mr. Morse is associate director of research on oil and gas production

R. A. Morse

Douglas Ragland

(Continued on page 515)

News of the Iron and Steel Division

Bylaw Changes Provide For Howe Memorial Lecture Committee

The following change in bylaws of the Iron and Steel Division was approved by the Division Executive Committee to provide for the proper functioning of the Howe Memorial Lecture Committee. Approval was given by the Board of Directors of The Metallurgical Society in January, and by the Board of Directors of AIME in February, 1961. Under Article VI, add new Section 6:

The Howe Memorial Lecture Committee shall consist of four members of the Division, one appointed each year for a term of four years by the Chairman of the ISD, subject to the approval of the Executive Committee. The member in his second year of service shall be Chairman of the Lecture Committee.

a. It shall be the responsibility of the Lecture Committee to select an outstanding scientific leader to present a lecture on a technical subject of particular interest to the Division at a meeting approximately two years following the time of his selection. The selection is subject to the approval of the Executive Committee, and the Division Secretary shall promptly thereafter report the action to the Program Committee. The lecturer-nominee shall be notified by written invitation prepared by the Division Secretary and signed by the President of The Metallurgical Society at least eighteen months prior to the date of the lecture.

b. The Lecture Committee shall be responsible for the arrangements of the lecture presented during its year of office. It also shall be responsible for the itinerary of the lecturer. Financial arrangements shall be subject to the approval of the Executive Committee. An appropriate citation shall be prepared by the Committee for presentation to the lecturer. The lecture shall be known as the Howe Memorial Lecture and the lecturer shall be known as the Howe Lecturer for that year.

Morris Cohen Selected To Present 1962's Howe Memorial Lecture

Morris Cohen, professor of metallurgy at Massachusetts Institute of Technology, has been selected to present the Howe Memorial Lecture in 1962. His lecture will be given on Tuesday, February 20, during the AIME Annual Meeting in New York.

ISD's Participation In 1961 Fall Meeting Is Announced

The Iron and Steel Division will sponsor two technical sessions on Tuesday, October 24, during the annual Fall Meeting of The Metallurgical Society, held in conjunction with the Metal Congress. The Fall Meeting will be housed at the Pick-Fort Shelby Hotel in Detroit.

The first session on *Breakdown of Cast Structures* will be sponsored by the Mechanical Working Committee. The second session on *Continuous Casting* will be sponsored by the Physical Chemistry of Steelmaking Committee.

Electric Furnace Conf. Will Be Held Dec. 6-8 In Pittsburgh

The 19th Annual Electric Furnace Conference will be held at the Penn-Sheraton Hotel, Pittsburgh, on December 6-8. The opening session on *Use of Vacuum and Inert Gas Atmospheres in Steelmaking* will be arranged by the Physical Chemistry of Steelmaking Committee. Subsequent sessions are scheduled on *Operating Metallurgy, Quality Improvements in Stainless Steel, Refractories, Effect and Control of Metal Temperatures,* and *International Developments.* Of particular interest to the *Special Arc* group are two sessions on *Ferro-Alloys* and a session on *Calcium Carbide and Phosphorus.*

The plant trips on the final day will be run to Jessop Steel Co., at Washington, Pa., and McConway and Torley, Pittsburgh.

Mechanical Working Conf. Set For Detroit January 17, 1962

The Fourth Annual Mechanical Working Conference will be held January 17, 1962 at the Pick-Congress Hotel in Chicago. The subject of the conference will be *Flat Rolled Products.*

The program will include papers on *Factors Affecting the Measurement of Strip Temperature by Thermocouple Roll* by Frank Luerssen of Inland Steel Co.; *Grain Orientation in Drawing Quality Steel* by R. H. Heyer of Armco Steel Corp.; *Strain Marking on Cold Rolled and Annealed Sheets* by J. F. Butler of Jones & Laughlin Steel Corp.; and *Minimized-Spangle Galvanized Sheets* by an author from Wheeling Steel Corp. Additional papers are being arranged.

NOHC & Blast Furnace Conferences Scheduled For Detroit, April 9-11

The 45th National Open Hearth Steel Conference, held in conjunction with the Blast Furnace, Coke Oven, and Raw Materials Conference, will be held at the Sheraton-Cadillac Hotel, Detroit, on April 9-11, 1962. A special program feature will be an International Symposium on *Oxygen Steelmaking.* The Acid Converter and Basic Oxygen Steel Committee will participate in developing the technical program.

Engineering Center Receives Support of ISD Conf. Committees

The Iron and Steel Division, through its Conference Committees, has given liberally to support the building fund for the new United Engineering Center. The amounts contributed to date are listed below:

Blast Furnace, Coke Oven, and Raw Materials Committee	$2,334.00
Electric Furnace Committee	2,000.00
Mechanical Working Committee	200.00
National Open Hearth Steel Committee	2,000.00
Chicago section, NOHC	500.00
Detroit section, NOHC	200.00
Southern Ohio section, NOHC	150.00
Total	$7,384.00

Several of the Committees have pledged additional support for 1962.

Proceedings of Past Years Still Available

Proceedings of Iron and Steel Conferences are still available for sale as indicated by accompanying table:

	Blast Furnace Proceedings	Electric Furnace Proceedings	Mechanical Working Proceedings	Open Hearth Proceedings
1947	N	A		N
1948	N	A		N
1949	N	A		N
1950	N	N		N
1951	A	N		N
1952	N	N		N
1953	N	A		A
1954	N	N		A
1955	N	N		A
1956	N	A		A
1957	A	A		N
1958	A	A		A
1959	A	A	B	A
1960	A	P	C	A
1961	P		P	P

Code

A—Available—AIME Members, $7.00 per copy; Non-Members, $10.00 per copy
B—Available—AIME Members, $3.00 per copy; Non-Members, $3.75 per copy
C—Available—AIME Members, $3.20 per copy; Non-Members, $4.00 per copy
N—No longer in print
P—In preparation

All orders should be sent to AIME Book Order Department, 29 West 39th Street, New York 18, N. Y., with the exception of non-member orders for Mechanical Working Conference Proceedings. The latter orders should be directed to: Interscience Publishers, 250 Fifth Avenue, New York, N. Y.

Officers and Committee Members

IRON AND STEEL DIVISION

Gerhard Derge, Chairman
J. J. Golden, Past Chairman
B. M. Larsen, Chairman-Elect
R. W. Shearman, Secretary-Treasurer

Executive Committee

1962: F. G. Anderko (Blast Furnace), H. L. Bishop (Publications), J. C. Fulton (Physical Chemistry of Steelmaking), C. M. Kay (National Open Hearth Steel), C. A. Lovgren (Membership), F. W. Luerssen (Program), G. C. Olson (Electric Furnace), P. H. Smith (Mechanical Working), A. B. Wilder (Acid Converter and Basic Oxygen Steel) **1962:** J. F. Elliott, T. F. Olt; **1963:** R. A. Lubker, C. T. Marshall; **1964:** R. D. Hindson, D. R. Loughrey.

Standing Committees

Howe Memorial Lecture: Maxwell Gensamer, '62, Chairman; C. E. Sims, '63 A. B. Wilder, '64, L. S. Darken, '65.

Robert W. Hunt Medal and Prize: D. C. Hilty, '62, Chairman; J. F. Elliott, '63; C. W. Hart, '64 W. M. Patterson, '65.

J. S. Johnson, Jr., Award: W. F. Huntley, '62, Chairman; C. F. Hoffman, '63; C. T. Marshall, '64; J. W. Duncan, '65; W. E. Marshall, '66.

Membership: C. A. Lovgren, Chairman; plus Membership Committees of the three Conference Committees.

Nominating: J. J. Golden, Chairman; James Chisholm, J. F. Elliott, L. W. Moore, C. F. Schrader, A. B. Wilder.

Program: F. W. Luerssen, Chairman; J. C. Fulton, Vice-Chairman; R. E. Boni, Secretary; C. W. Conn (NOHC), H. E. Harris (Blast Furnace), C. G. Mickelson (Electric Furnace), A. B. Wilder (Acid Converter and Basic Oxygen Steel), P. H. Smith (Mechanical Working).

Publications: H. L. Bishop, Chairman; R. E. Boni, F. C. Langenberg, J. B. Wagstaff, T. V. Wainwright.

Scope of Technical Committees: J. J. Golden, Chairman; Gerhard Derge, C. M. Kay, G. C. Olson, W. O. Philbrook, R. E. Powers, A. W. Thornton, A. B. Wilder.

Technical Committees

Acid Converter and Basic Oxygen Steel: A. B. Wilder, Chairman; C. C. Benton, E. P. Best, Gerhard Derge, R. F. Dierker, S. J. Dougherty, Ralph Duffett, H. C. Dunkle, R. E. Edwards, George Grosvenor, J. H. Kelley, W. H. Mayo, George McMorran, F. J. McMulkin, J. F. O'Brien, Charles J. Petry, L. J. Sauter, M. J. Smith, J. M. Stone, G. M. Yocom, J. A. Glasgow.

* * *

Blast Furnace, Coke Oven, and Raw Materials (April '61-April '62): F. C. Anderko, Chairman; James Chisholm, Past-Chairman; W. F. Huntley, Vice-Chairman, '62; W. O. Bishop, Vice-Chairman, '63; D. C. Brown, Secretary; R. W. Shearman, Treasurer.
Executive Board: John Poast, Jr., '62; A. D. Shattuck, '62; J. S. McMahan, '63; E. R. Dean, '64; V. J. Nolan, '65; R. H. White, '65.

* * *

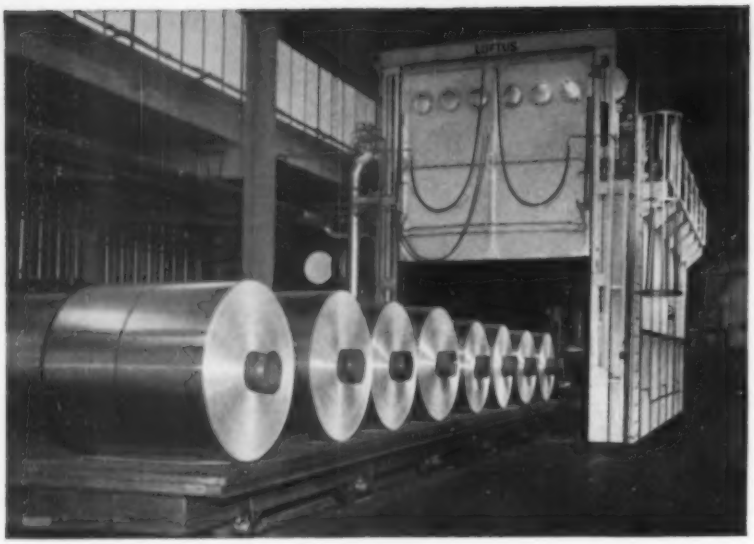
Electric Furnace: Executive: G. C. Olson, Chairman; P. R. Gouwens, Past-Chairman; R. W. Shearman, Secretary-Treasurer; W. C. Kollman, '61; H. O. Beaver, '62; W. J. Mathews, '63 (Ingots); A. F. Gross, '61; Robert Thompson, '62; A. J. Kiesler, '63 (Castings); A. F. Sprankle, '61; W. M. Kelly, '62; W. J. Fulton, '63 (Special Arc); L. H. Banning, '61 (Research).
Conference: C. G. Mickelson, Chairman; Frank St. Vincent, 1st Vice-Chairman; R. W. Farley, 2nd Vice-Chairman; F. I. Marshall, '61; W. E. Hart, '61; B. H. Brown, '62; J. M. Ford, '63; A. L. Lehman, '63 (Ingots); John McBroom, '61; G. J. Grott, '62; W. E. Brandt, '62; J. Fuqua, '62; S. E. Wolosin, '63 (Castings); E. T. Johnson, '61; A. L. Ascik, '63 (Special Arc); N. H. Keyser, '61 (Research); A. E. Bickell, '61 (Refractories and Molds); G. D. Lawrence, '62 (Furnaces and Equipment); J. J. Green, '63 (Electrodes and Alloys).

* * *

Mechanical Working: P. H. Smith, Chairman; C. F. Schrader, Past Chairman; T. E. Dancy, Vice Chairman; J. F. Griffin, Secretary-Treasurer.
Executive Board: W. A. Backofen, D. J. Blickwede, T. G. Bradbury, E. W. Earhart, D. A. Edgecombe, A. G. Forrest, N. B. Juster, E. W. Mahaney, L F. Weitzenkorn.

* * *

National Open Hearth Steel (April '61-April '62): C. M. Kay, Chairman; L. W. Moore, Past-Chairman; C. W. Conn, Vice-Chairman; R. W. Shearman, Secretary-Treasurer.
Executive Board: H. B. Emerick, '62; T. G. Harkins, '62; T. V. Wainwright, '62; G. L. Owens, '63; H. R. Loxterman, '63; A. A. Kappenhagen, '63; R. G. Phelps, '64; P. G. Sammet, '64; M. J. Smith, '64; G. R. Fitterer, '65; G. A. Grosvenor, '65; L. B. Lindemuth, '65; A. K. Moore, '65; E. B. Snyder, '65.
Physical Chemistry of Steelmaking: J. C. Fulton, Chairman; D. C. Hilty, Past-Chairman; F. C. Langenberg, Vice-Chairman; D. W. Murphy, Secretary.



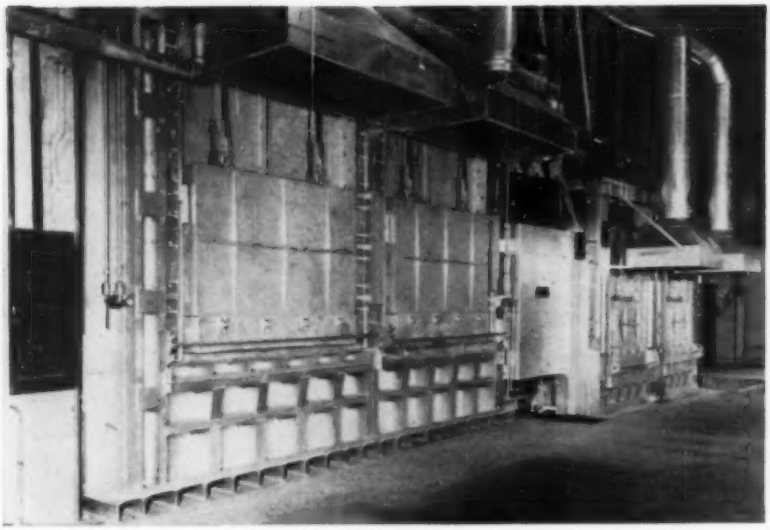
LOFTUS *Aluminum* FURNACES

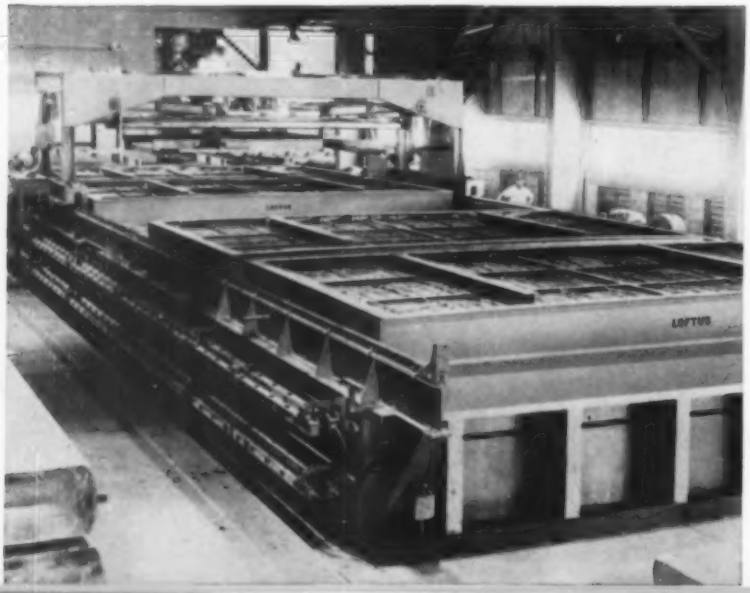
for
melting, holding,
reheating, annealing,
homogenizing

The many repeat orders for Loftus furnaces are the best evidence of customer satisfaction. Loftus furnaces offer:

- **High Production**
- **Economical Operation**
- **Low Maintenance**
- **Rugged Construction**

Whether building or expanding, you too can benefit from the wealth of experience available from Loftus.





Loftus custom-builds complete plants and specializes in furnaces of all types and sizes for both ferrous and non-ferrous metals. Whatever your requirements, it will pay you to call on the engineering and construction know-how developed by Loftus over more than two decades of service to American metal producers.

From first heat to heat treat, look to

LOFTUS

Engineering Corporation

1 Gateway Center, Pittsburgh 22, Pa.

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME members on May 31, 1961, was 34,870; in addition 2,038 Student Members were enrolled.

ADMISSIONS COMMITTEE

W. L. Brytczuk, Chairman; S. C. Carapella, Jr.; J. W. Hanley; T. D. Jones; H. C. Larson; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Adams, Patrick F., Bethlehem, Pa.
Borrebach, Edwin J., East Pittsburgh, Pa.
Bosshardt, Hans J., Mahr Tunnel, Peru, S.A.
Brion, Dalton F., Bethlehem, Pa.
Caum, Jesse W., Philadelphia, Pa.
Crawford, Charles W. J., London, England
Davis, Charles A., Homestead, Pa.
Death, Frank S., Tonawanda, N. Y.
Devasher, Roy O., Granite City, Ill.
DeWeese, Richard O., Niagara Falls, N. Y.
Ford, Harold L., Denver, Colo.
Gittins, Arthur W., Steubenville, Ohio
Gribbie, Frank E., Braddock, Pa.
Gross, John W., Euclid, Ohio
Hahn, Elmer, Pittsburgh, Pa.
Harstone, Jack, Dundas, Ont., Canada
Ivey, John R., Ajo, Ariz.
Kun, Zoltan K., Oak Park, Ill.
Mader, Charles K., Cold Spring, N. Y.
McElhaney, Clifford J., Pittsburg, Calif.
Michard, Jean Alex, Moselle, France
Ramakrishna, Venkatachari, Cambridge, Mass.
Rothenthaler, Nickolas E., Dearborn, Mich.
Shaw, Billie C., Kansas City, Mo.
Smith, John H., Willoughby, Ohio
Smith, John S., Jr., Baytown, Tex.
Stout, R. Philemon, Philadelphia, Pa.
Szalay, Frank M., Homestead, Pa.
Thomas, Gareth N., Berkeley, Calif.
Wells, Clifford H., Clinton, Conn.

Associate Members

Baxter, Gordon J., Chicago, Ill.
Carlson, Arthur K., New York, N. Y.
Edwardson, Heran B., Pittsburgh, Pa.
Ellison, Matthew L., Springfield, Pa.
Ermini, Erminio, Piombino, Livorno, Italy
Fallon, Thomas F. III, Clayton, Mo.
French, Lowell L., Jr., Pittsburgh, Pa.
Gardner, Paul K., New York, N. Y.
Gates, John S., Philadelphia, Pa.
Ginter, James W., Woodbridge, N. J.
Pozefsky, Leo, Bethlehem, Pa.
Reintjes, Harold, New York, N. Y.
Russell, Robert B., Pittsburgh, Pa.
Schneider, Richard F., Dearborn, Mich.
Shober, Pemberton H., Philadelphia, Pa.
Stevens, William K., Mexico, Mo.
Tatum, G. B., Lakewood, Ohio
Trullinger, Park R., Harrisburgh, Pa.
Weymouth, Edward A., Detroit, Mich.
Anderson, Leonard R., Buffalo, N. Y.

Junior Members

Armstrong, Ronald W., Pittsburgh, Pa.
Bickley, William H., Columbus, Ohio
Dolde, Richard H., Fair Oaks, Pa.
Gupta, Ishwar N., Bethlehem, Pa.
Hanley, Patrick J., Natrona Hts., Pa.
Hitchon, John W., Saint Germain-en-laye, France
Kern, Frederick W., Homestead, Pa.
Lawrence, Robert L., Phillipsburgh, N. J.
Marchant, Ambrose F., Gary, Ind.
Mesaros, Charles, Pittsburgh, Pa.
Pratt, H. Raymond, Jr., Monroeville, Pa.
Rohatgi, Virendra, Delhi, India
Snowball, Robert F., Vancouver, B. C., Canada
Tetarway, Amar N., Bethlehem, Pa.

REINSTATEMENT—MEMBER

Barber, James E., Sault Ste. Marie, Ont., Canada
Demos, Anthony C., Philadelphia, Pa.

REINSTATEMENT—CHANGE OF STATUS

Junior to Member

Blackwell, Douglas C., New York, N. Y.

Student to Member

Kondas, Edward G., Cleveland, Ohio

SPECIAL REINSTATEMENT

To Member

Tuwiner, Sidney B., Baldwin, L. I., N. Y.

To Junior

Wissing, Thomas J., Waukegan, Ill.

To Student

Leak, V. G., Minneapolis, Minn.

RE-ELECTION TO MEMBER

McKee, Keith H., St. Clair Shores, Mich.

CHANGE OF STATUS

Associate to Member

Clark, Rudy E., Vancouver, Wash.
Eisner, Robert L., Pittsburgh, Pa.
Grzywacz, Wladyslaw K., Stratford, Conn.
Lieberman, David S., Urbana, Ill.
McCune, Harry E. III, Natrona Hts., Pa.

NECROLOGY

Year Elected	Name	Date of Death
1946	Brennan, Joseph H.	Apr. 19, 1961
1944	Dannatt, Cecil W.	Unknown
1956	Huber, Albert	Unknown
1930	Jameson, J. A.	Jan. 17, 1961
1952	Jenkins, J. B.	Unknown
1952	Neighbors, Glen R.	Unknown
1939	Oliver, Mac D., Jr.	Unknown
1912	Roddewig, Geo. W.	Mar. 15, 1961
1947	Wright, John K.	Mar. 4, 1961

Lewis B. Lindemuth

Lewis B. Lindemuth died April 9, after a short illness, at St. Croix in the Virgin Islands. He was 73. He had retired to the Caribbean five years ago, and lived there on his boat, a 40-ft ketch.

Mr. Lindemuth was known in the steel industries in the US and abroad as an open hearth design and operating engineer. His career as a consultant began after World War I, and took him to many foreign countries.

An active AIME member for many years, perhaps Mr. Lindemuth's most significant contribution was his part in the formation of the National Open Hearth Committee which was begun in 1924 as a means for independent steel companies to exchange technical operating information. He was the first Secretary of the NOHC, and with J. V. W. Reynders, then AIME President, was instrumental in organizing the first meeting of the NOHC in Pittsburgh in 1925. Twenty-six persons attended.

Mr. Lindemuth was born in 1887 in Wichita, Kan., earned a degree at Pennsylvania State University in 1909, and began as a pit laborer in the Open Hearth and Bessemer depts. of the Pennsylvania Steel Co. (now Bethlehem Steel) in Steelton, Pa. He gained early technical experience under H. H. Campbell of that company. During World War I, he supervised duplex operations, also the crucible, electric furnace, alloy foundry, and tool-steel heat-treating departments at Bethlehem, Pa. He left the company with F. D. Carney, general superintendent, to form a consulting firm in 1918.

AIME Directors

(Continued from page 511)

and transportation for Gulf Research & Development Co., Pittsburgh. He graduated from Oklahoma University and received a M.S. in petroleum and natural gas engineering from Pennsylvania State University.

Mr. Morse has been Chairman of both the AIME Publications Committee and the Technology Committee. He was a Vice President in 1960.

* * *

Douglas Ragland is the Society of Petroleum Engineers' second nominee for a three-year term as a Director of AIME. Mr. Ragland is engineering manager of Humble Oil & Refining Co.'s production dept.

A graduate of Rice University, Mr. Ragland served three years as a member of the SPE Education Committee, two years as SPE representative to the ECPD Corps of Inspectors, and four years as SPE's representative to ECPD. He is the AIME representative to the Executive Committee of ECPD. He has also served on special AIME committees to make recommendations to the AIME Board on engineering registration, to develop interest in the earth sciences and mineral industries among high school students, and to further inter-society cooperation.

Prices Are Reduced For Six Volumes on Nuclear Metallurgy

The price for the first six volumes of *Nuclear Metallurgy* papers covering several years of technical presentations at meetings has been reduced, according to an announcement by The Metallurgical Society. The six-book set is available to members for $12, and to non-members for $18.

The set of books comprises a 600-page nuclear metallurgy reference library based on papers given before Institute of Metals Division sessions at Fall and Annual Meetings. Included are symposia on *Behavior of Materials in Reactor Environment*; *Effects of Radiation on Metals*; *Uranium and Uranium Dioxide*; *Fabrication of Fuel Elements*; and *Effects of Irradiation on Fuels and Fuel Elements.*

The volumes may be ordered from AIME Book Order Department, 29 West 39th Street, New York 18, N. Y.

Coming Events

June 25-30, 1961, ASTM National Meeting, Chalfonte-Haddon Hall, Atlantic City, N. J.

June 26, 1961, ASTM, 64th Annual Meeting, Chalfonte-Haddon Hall, Atlantic City, N. J.

Aug. 7-9, 1961, Annual Conference on Applications of X-Ray Analysis, Park Lane Hotel, Denver, Colo.

Aug. 30-Sept. 1, 1961, AIME Third Technical Conference on Semiconductors, Ambassador Hotel, Los Angeles.

Aug. 31, 1961, Chicago Section, NOHC, Annual Golf Outing, Gleneagles Country Club.

Sept. 17-20, 1961, Commemoration of the 50th Anniversary of Froth Flotation, Cosmopolitan Hotel and Brown Palace Hotel, Denver, Colo.

Oct. 2, 1961, Chicago Section, NOHC, Fall Technical Dinner Meeting, Phil Smidt's Restaurant, Chicago.

Oct. 2-3, 1961, 29th Annual Meeting, Engineers' Council for Professional Development, Sheraton Hotel, Louisville, Ky.

Oct. 5-6, 1961, Southwestern Section, NOHC, Annual Fall Meeting, President Hotel, Kansas City, Mo.

Oct. 17-Nov. 7, 1961, Visit of the Iron & Steel Institute (United Kingdom) to the United States.

Oct. 20, 1961, Eastern Section, NOHC, 15th Annual Technical Conference, Warwick Hotel, Philadelphia.

Oct. 23-26, 1961, Fall Meeting of The Metallurgical Society of AIME, Pick-Fort Shelby Hotel, Detroit.

Nov. 3, 1961, Pittsburgh Section, 16th Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh, Pa.

Nov. 13-16, 1961, Seventh Annual Conference on Magnetism and Magnetic Materials, Hotel Westward Ho, Phoenix, Ariz.

Nov. 29-30, 1961, Iron and Steel Institute (U.K.) Fall General Meeting on Future of Ironmaking in the Blast Furnace, London.

Dec. 4, 1961, Annual Meeting, Arizona Section, AIME, Pioneer Hotel, Tucson, Ariz.

Dec. 6-8, 1961, 19th Electric Furnace Conference, Penn-Sheraton Hotel, Pittsburgh, Pa.

Jan. 17, 1962, AIME Mechanical Working Conference, Pick-Congress Hotel, Chicago, Ill.

Feb. 18-22, 1962, AIME Annual Meeting, New York, N. Y.

Apr. 9-11, 1962, NOHC Blast Furnace, Coke Oven, and Raw Materials Conference, Sheraton-Cadillac Hotel, Detroit, Mich.

Apr. 12-14, 1962, AIME Pacific Southwest Minerals Industry Conference, Palace Hotel, San Francisco, Calif.

April 26-28, 1962, AIME Pacific Northwest Metals and Minerals Conference, Ben Franklin Hotel, Seattle, Wash.

ADVERTISER'S INDEX

Air Reduction — *G. M. Basford Co.*	*
Ajax Magnethermic — *Meek & Thomas, Inc.*	*
American Brake Shoe — *Fuller & Smith & Ross, Inc.*	*
American Potash & Chemical Corp. — *C. Franklin Brown*	*
Bailey Co., Wm. M. — *Downing Industrial Adv., Inc.*	470
Baird Atomic — *F. P. Walther Jr. & Associates*	*
Bell Telephone Labs. — *N. W. Ayer & Son, Inc.*	*
Buehler Ltd. — *Kreicker & Meloan, Inc.*	457
Curtiss-Wright Corp. — *Hayden Adv., Inc.*	464
Dravo Corp. — *Ketchum, MacLeod & Grove Inc.*	*
Foote Mineral Co. — *Harris D. McKinney, Inc.*	*
Frankel Co., Inc. — *Denham & Co.*	*
General Motors Corp. — *Campbell-Ewald Co.*	*
General Refractories Co. — *Lewis & Gilman, Inc.*	*
General Telephone & Electronics — *Deutsch & Shea, Inc.*	*
Great Lakes Carbon Co. — *Davis, Parsons & Strohmeier, Inc.*	Cover III
Harbison Walker — *Downing Industrial Ad. Inc.*	*
Hamler Industries, Inc. — *Aves Advertising, Inc.*	*
Hevi-Duty Electric Co. — *Bert S. Gittins Adv. Inc.*	*
International Business Machines — *Benton & Bowles, Inc.*	*
International Nickel Co. — *McCann-Marschalk Co.*	*
Jones & Laughlin Steel Corp. — *John Patrick Starrs, Inc.*	*
Kaiser Engineers — *L. C. Cole Co. Inc.*	Cover II
Lectromelt Furnace Div. — **McGraw-Edison Co.** — *The Griswold-Eshleman Co.*	*
Linde Co. — *J. M. Mathes, Inc.*	*
Lockheed Missiles & Space Div. — *Hal Stebbins Inc.*	*
Loftus Engineering — *Marsteller, Rickard, Gebhardt & Reed, Inc.*	514
McKee, Arthur G. — *Mills Adv.*	463
Molybdenum Corp. of America — *Smith, Taylor & Jenkins, Inc.*	*
Morgan Construction Co. — *Davis Press, Inc., The*	*
Ohio Ferro-Alloys Corp. — *Frease & Shorr Adv.*	*
Pennsylvania Engineering Co. — *Downing Industrial Adv., Inc.*	*
Philips Electronic Instruments — *Anders Associates Adv.*	*
Radio Corporation of America — *Al Paul Lefton Co., Inc.*	*
Ramtite Co., The — *Leo P. Bott, Jr. Adv.*	*
Research Specialties — *Associated Adv. Counsellor*	*
Roots-Connersville Blower Div. — *Persons Adv.*	*
Robinson Clay Products Co. — *Norman Malone Associates*	*
Smith-Douglass Co., Inc. — *Chesapeake Adv.*	*
Sylvania Electro Products, Inc. — **Chemical & Metallurgical Div.** — *Kudner Agency Inc.*	*
Taylor Sons Co., The Chas. — *The Keelor & Stites Co.*	*
M. H. Treadwell — *John Patrick Starrs Inc.*	*
Thompson-Ramo-Wooldridge Inc. — *Meldrum & Fewsmith Inc.*	*
Union Carbide Metals Co., Div. — **Union Carbide Corp.** — *J. M. Mathes, Inc.*	455
U.S. Steel Corp. — **Columbia-Geneva Steel Div.** — **Tennessee Coal & Iron Div.** — **U.S. Steel Export Co.** — **U.S. Steel Supply Div.** — *Batten, Barton, Durstine & Osborn, Inc.*	*
Unitron Instrument Div. — **United Scientific Co.** — *Larcom Randall Adv., Inc.*	Cover IV
Wah Chang — *Kelly Nason, Inc.*	*
Whiting Corp. — *Schmidt & Sefton Adv.*	*
Wyman-Gordon Co. — *The Davis Press, Inc.*	472

* Previous issues.

Stainless is on the move

—in building, communication, transportation, defense

and when you're producing stainless steels GLC ELECTRODES WILL LOWER MELT-TON COSTS

Our electrode customers are now reaping the benefits of advances we have made in graphite technology and manufacturing techniques.

Their melt-ton costs are being reduced by better all-round electrode performance which shortens furnace down-time, steps up production.

Our electrodes are of excellent quality—and our service technicians are swiftly on the job when wanted. You'll find it pays—and pays well—to specify GLC electrodes.

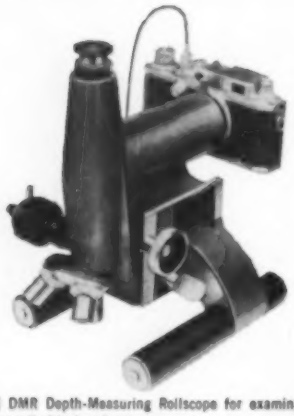
PRODUCTS YOU CAN TRUST — GLC — ELECTRODE DIVISION

GREAT LAKES CARBON CORPORATION

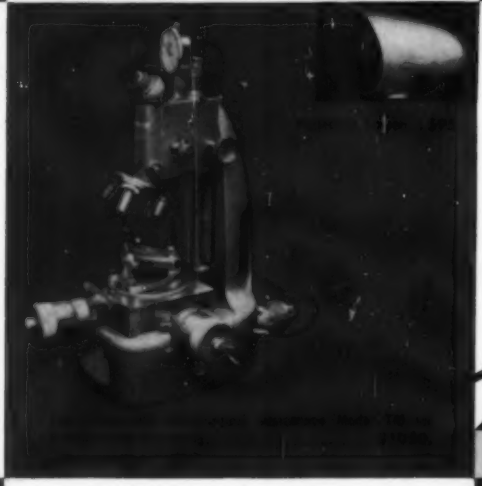
18 EAST 48TH STREET, NEW YORK 17, N.Y. OFFICES IN PRINCIPAL CITIES

If **METALLURGY** is your field, **UNITRON** is your microscope

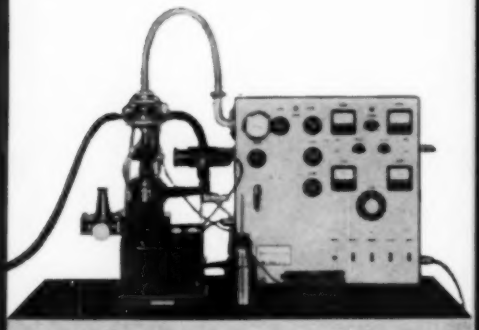
Model MMA.....$149. Model MMU.....$287.

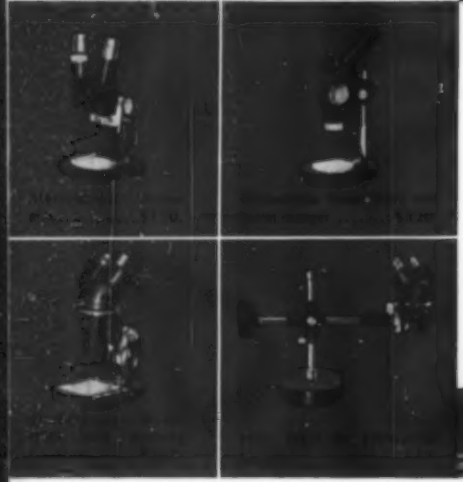


Model DMR Depth-Measuring Roliscope for examination of large or cylindrical surfaces.....$445.



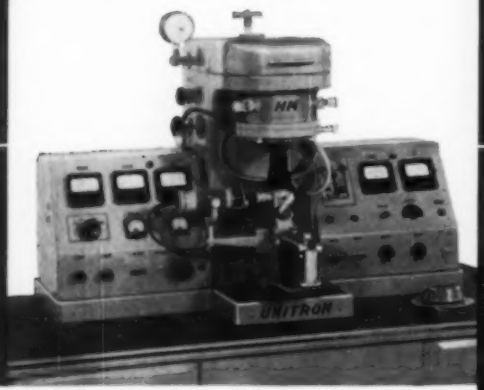
UNITRON'S Complete Laboratory Installation for High-Temperature Metallography with Metallograph and HVC-3 Control and Power Station.

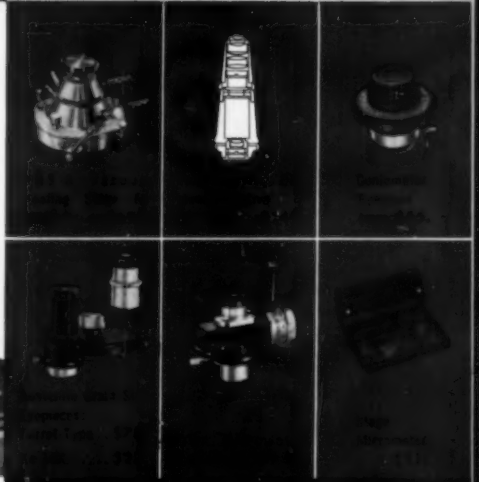




UNITRON'S Research Installation for High-Temperature Microscopy, Desk Model HM

(Write for price and complete specifications)





UNITRON IS YOUR **COMPLETE** SOURCE FOR MICROSCOPES

to meet every metallurgical application . . . from low-power macro to high-power micro examinations, right on through to advanced research in high temperature studies of the new metals in the space age. And when it's time to balance your equipment budget against your needs, UNITRON prices will be among the best news of all.

TRY A *UNITRON* IN YOUR LAB . . . **FREE,** FOR 10 DAYS

A salesman's demonstration gives you only about 30 minutes to examine a microscope . . . hardly the best conditions for a critical appraisal. But, UNITRON'S Free 10-Day Trial allows you to use the microscope in your own lab and put it through its paces on your own particular problem. Use the coupon to ask for a no-obligation, prepaid trial. And if you want more details on these and other UNITRON Microscopes, use the coupon to request a complete catalog.

UNITRON

INSTRUMENT COMPANY • MICROSCOPE SALES DIV.
66 NEEDHAM ST. • NEWTON HIGHLANDS 61, MASS.

☐ I want a FREE 10-day trial of Model.....

☐ Send me your catalog No. 10-R

NAME DEPT.

COMPANY

ADDRESS

CITY STATE